IMPERIAL INSTITUTE

MONOGRAPHS ON MINERAL RESOURCES WITH SPECIAL REFERENCE TO THE BRITISH EMPIRE

PREPARED UNDER THE DIRECTION OF THE MINERAL RESOURCES COMMITTEE WITH THE ASSISTANCE OF THE SCIENTIFIC AND TECHNICAL STAFF OF THE IMPERIAL INSTITUTE

LEAD ORES

BY

T. C. F. HALL, M.Inst.M.M., F.G.S.

LONDON

JOHN MURRAY, ALBEMARLE STREET, W.

IMPERIAL INSTITUTE

MINERAL SECTION

THE Imperial Institute is a centre for the exhibition and investigation of minerals with a view to their commercial development, and for the supply of information respecting the sources, composition and value of minerals of all kinds.

The Imperial Institute is provided with Research Laboratories for the investigation, analysis and assay of minerals, and undertakes reports on the composition and value of minerals for the information of Governments and producing companies and firms, in communication with the principal users in the United Kingdom and elsewhere in the Empire.

Important minerals from within the Empire are exhibited in the respective Courts of the Public Exhibition Galleries, and also in the Mineral Reference Collections of the Institute.

A special staff is engaged in the collection, critical revision and arrangement of all important information respecting supplies of minerals especially within the Empire, new methods of usage and other commercial developments.

Articles on these and related subjects are periodically published in the *Bulletin of the Imperial Institute*, and Monographs on special subjects are separately published under the direction of the Committee on Mineral Resources.

IMPERIAL INSTITUTE

Advisory Committee on Mineral Resources

The Right Hon. VISCOUNT HARCOURT, D.C.L. (*Chairman*).
*Admiral SIR EDMOND SLADE, K.C.I.E., K.C.V.O. (nominated by the Admiralty), (*Vice-Chairman*).
EDMUND G. DAVIS, Esq.
*WYNDHAM R. DUNSTAN, Esq., C.M.G., LL.D., F.R.S., Director of the Imperial Institute.
J. F. RONCA, Esq., M.B.E., A.R.C.S., Department of Industries and Manufactures (nominated by the Board of Trade).
*Professor J. W. GREGORY, F.R.S., Professor of Geology, University of Glasgow, formerly Director of Geological Survey, Victoria, Australia.
Sir ROBERT HADFIELD, Bart., F.R.S., Past-President, Iron and Steel Institute.
Captain A. L. ELSWORTHY, Intelligence Department, War Office (nominated by the War Office).
W. W. MOYERS, Esq. (Messrs. A. Watson & Co.), Liverpool.
R. ALLEN, Esq., M.A., B.Sc., Imperial Institute (*Secretary*).

* Members of Editorial Sub-Committee.

MINERAL SECTION

Principal Members of Staff

Superintendent

R. ALLEN, M.A. (Cantab.), B.Sc. (Lond.) M.Inst.M.M.

Assistant Superintendent

S. J. JOHNSTONE, B.Sc. (Lond.), A.I.C.

Senior Assistant

W. O. R. WYNN, A.I.C.

Assistants

S. BANN.
F. H. BELL.
H. BENNETT, B.Sc. (Lond.).
A. T. FAIRCLOTH.
R. C. GROVES, M.Sc. (Birm.).
F. HALSE, A.R.S.M., M.Inst.M.M.

PREFACE

THE Mineral Resources Committee of the Imperial Institute has arranged for the issue of this series of Monographs on Mineral Resources in amplification and extension of those which have appeared in the *Bulletin of the Imperial Institute* during the past fifteen years.

The Monographs are prepared either by members of the Scientific and Technical Staff of the Imperial Institute, or by external contributors, to whom have been available the statistical and other special information relating to mineral resources collected and arranged at the Imperial Institute.

The object of these Monographs is to give a general account of the occurrences and commercial utilization of the more important minerals, particularly in the British Empire. No attempt has been made to give details of mining or metallurgical processes.

HARCOURT,
Chairman, Mineral Resources Committee.

IMPERIAL INSTITUTE,
LONDON, S.W.7.
October 1920.

CONTENTS

NOTE: *Numerals in square brackets in the text refer to the Bibliography at the end.*

LEAD ORES

CHAPTER I

LEAD ORES: THEIR OCCURRENCE, CHARACTERS AND USES

INTRODUCTION

LEAD, although one of the commoner of the base metals, is present in the earth's crust only to the extent of a fraction of 1 per cent. of the whole. In workable deposits, however, the proportion is much higher owing to a natural concentration of material. Lead is closely associated in nature with zinc, and their primary or sulphide ores commonly occur together. Zinc ores are more soluble than lead ores, hence in the zone of oxidation the former have frequently been leached away, and practically pure lead ore may occur above water-level. In this way were formed the lead carbonate deposits of Leadville and elsewhere. Such bodies, however, give place to mixed lead and zinc sulphides in depth. Lead in nature is also intimately associated with silver, and many lead deposits are also the repositories of valuable silver ores. Galena itself is frequently argentiferous and may be regarded as the chief source of the world's supply of silver.

Owing to this association a large number of deposits are conveniently referred to collectively as silver-lead-zinc deposits. The vertical distribution of the ores of the different metals suggests that the deposition of zinc takes place under conditions of higher temperature and pressure than those of lead, whilst silver is more closely associated with the latter metal than with the former. The ores thus tend to occur in zones, though their limitation is necessarily very irregular and subject to considerable overlapping. Zinc, as a general

rule, predominates in the lower zone of mineralization, below the main lead occurrence, while silver occurs more particularly in the upper zone, although, in small quantity, it may be generally distributed with the other metals.

The predominant mineral in a deposit of this class will depend, therefore, upon the extent to which the original ore body has been eroded. Thus we may regard those deposits carrying large bodies of rich silver ores (often accompanied by gold) with only subordinate amounts of galena as representing a more superficial or later type of mineralization than is the case with others carrying chiefly lead or zinc. Such deposits are a marked feature of the American Cordilleran region, where they are associated chiefly with Tertiary lavas, rocks which, comparatively speaking, have undergone but little erosion since their formation at a late geological period. The contained veins may well represent, therefore, the upper zone of a mineral sequence characterized by the predominance of lead and zinc at greater depths. Indeed, in many of these veins the mining of lead has succeeded that of silver. Conversely, it has been suggested that there is good evidence for believing that the well-known lead-bearing veins of the Freiberg district represent deeper portions of similar deposits, the upper parts of which have been eroded away. Again, it is common knowledge that many deposits formerly worked for lead ore have, with increased depth, produced mainly zinc ore.

It is obvious that the vertical distribution of the metals and the limitation of their ores to particular horizons is of great economic significance. It is especially a subject for careful consideration in connection with the re-opening of old mines.

Lead-bearing Minerals

Lead as a native metal is of exceedingly rare occurrence, and is always of a secondary nature, having been reduced from some pre-existing compound.

The principal ore is the sulphide, *galena*. Other ores occurring in sufficiently large quantities to be mined are *cerussite* and *anglesite*, but these belong to the oxidized or

superficial zone. A basic sulphate containing lead and iron, *plumbojarosite,* though a rare mineral, occurs in certain mines in Utah in sufficient abundance to be mined [78]. The red oxide, *minium,* Pb_3O_4, and the yellow oxide, *massicot,* PbO, are comparatively rare minerals. The phosphate of lead, *pyromorphite,* $3Pb_3(PO_4)_2PbCl_2$, and the arsenate, *mimetite,* $3Pb_3(AsO_4)_2PbCl_2$, (green lead ores), commonly occur with other secondary lead minerals, although usually only in small quantity. The closely allied vanadate, *vanadinite,* $3Pb_3(VO_4)_2PbCl_2$, may be regarded as an ore of vanadium. The following are of occasional occurrence: the chromate, *crocoisite,* $PbCrO_4$, the molybdate, *wulfenite,* $PbMoO_4$, and the tungstate, *stolzite,* $PbWO_4$. In addition to the above there are numerous other lead-bearing minerals, including tellurides, selenides, oxychlorides, silicates, etc., which are of mineralogical interest only; and of recent formation are the group of oxychlorides (*laurionite,* etc.) which have been formed by the action of sea-water on the ancient slag-heaps of Laurium, in Greece.

Galena.—Lead sulphide, PbS (Pb 86·6 per cent). This, the common ore of lead, is of a lead-grey colour, and has a bright metallic lustre on fracture. It crystallizes in the cubic system, and has a perfect cubic cleavage. It is often massive in granular aggregates. A finely granular form, known as steel ore, probably results from secondary deposition, and is frequently rich in silver. Hardness = 2·5; specific gravity = 7·5.

Silver is always present in galena, but the quantity greatly varies and some ores contain only traces, though the amount is seldom less than 0·01 per cent. It may reach 0·25 per cent. or even higher. It may be stated generally that galena in large crystals, or in coarse grains, is usually poor in silver, while galena in small crystals, or in fine grains, is frequently rich in silver. The quantity of silver present is usually reckoned in ounces troy per ton of ore, and ores averaging 30 oz.* or over per ton are considered valuable, and known as argentiferous ores. Argentiferous galena sometimes contains gold. Other impurities found in galena are zinc, cadmium, iron, copper and antimony. Besides blende pyrite and chalcopyrite are frequent associates. Although galena is less

* About 0·1 per cent.

prone to alteration than most sulphides, it may be accompanied in the oxidation zone by cerussite, anglesite, pyromorphite, etc., or even may be entirely replaced by the first two minerals.

Jamesonite, $2PbS,Sb_2S_3$ (Pb 50·8, Sb 29·5 per cent.), *boulangerite,* $5PbS,2Sb_2S_3$ (Pb 55·4, Sb 22·8 per cent.), and *bournonite,* $3(PbCu_2)S.Sb_2S_3$ (Pb 42·6, Sb 24·7 per cent.), are lead-antimony minerals, but the last, containing 13 per cent. of copper, is sometimes mined as an ore of copper. Jamesonite, associated with arsenopyrite, pyrrhotite and blende, occurs as a replacement of limestone at Zimapan, in Mexico [59].

Cerussite, or white lead ore, $PbCO_3$ (Pb 77·5 per cent.).—This ore—the carbonate—often occurs in considerable masses, associated with oxides of iron and manganese. It is colourless to white or grey, often translucent, with a brilliant adamantine lustre. It crystallizes in the orthorhombic system, and occurs usually in prismatic crystals, often forming fibrous and radiating aggregates with a silky appearance. It is found also in granular or compact masses. It is very brittle. Hardness, 3 to 3·5; specific gravity, 6·5.

It was formerly the principal ore at Leadville (Colorado), and has been found in considerable bodies in Pima county (Arizona), Cœur d'Alene (Idaho), Broken Hill (N.S.W.) and Mexico (Sierra Mojada, Santa Eulalia, etc.).

Anglesite, or lead vitriol, $PbSO_4$ (Pb 68·3 per cent.).—This mineral has a more resinous lustre, and is softer and lighter than cerussite. Hardness, 2·7 to 3; specific gravity, 6·3. Its crystals are usually tabular or pyramidal. It is rarer than cerussite, and is readily transformed into the carbonate. Considerable quantities have been obtained from Leadville, Arizona, California and Mexico (Campo Morado, etc.). It was first found by Withering at the Parys Mine, Anglesea, from which place it takes its name.

Genesis and Mode of Occurrence of Lead Ores

Lead ores occur in *veins* and *lodes*; as *metasomatic replacements,* mainly in limestone and dolomite; as *contact deposits*; and as *disseminations* in sandstone and shale. The last-

named are comparatively unimportant. It has been estimated that about half the world's production of lead ore comes from metasomatic deposits.

Vein deposits.—In these the ore occurs in infilled fissures, which served as channels for the circulation of lead-bearing solutions from magmatic or other sources. Frequently, however, the vein filling is accompanied by considerable replacement of the country rock. The distribution of the ore in the fissures is often closely related to the character of the enclosing rock. Thus at Snailbeach Mine, Shropshire, the ore-shoots occur in grit, and there is complete impoverishment in soft shale, which occurs in bands alternating with the former rock. Again, in the north of England the lodes are lead-bearing in limestone and chert, and to a much less extent in sandstone, but are rarely productive in shale. Lead veins vary in width from a few inches to several feet, and some have been traced for miles, though this must be regarded as exceptional. Many have been worked to a depth of several thousand feet.

As already pointed out, lead veins almost invariably carry zinc ore as well, principally in depth. Other associations are pyrite and chalcopyrite, and the gangues are quartz, calcite, dolomite, siderite, fluorspar or barytes. These minerals are subject to much local variation and one, to the more or less exclusion of the others, is usually characteristic of a particular district or group of veins. Quartz is found especially in those veins which carry much chalcopyrite, and, when much silver is present, the gangue is characteristically a carbonate or barytes.

As galena is highly insoluble it may occur with but little alteration up to the surface, but under special conditions considerable quantities of carbonate (cerussite) or of sulphate (anglesite) may be found. Such ores, however, occur more especially in limestone replacement deposits, where the conditions for deep oxidation are more favourable. Where the galena carries much silver, an enrichment of this metal in the secondary zone is often a conspicuous feature, and native silver may occur upon the fractures and surfaces of the galena. Rich silver ores also may be present.

Metasomatic deposits.—These constitute a very important class and contribute, at the present time, by far the greater part of the world's output of lead ore. These deposits have been considerably developed in the United States of America, where many of them are of large dimensions and furnish some of the most remarkable occurrences of lead ore known.

This type of ore body has been formed by a replacement of limestone or dolomite by galena, the sulphide of lead having most probably been carried in solution by alkaline sulphides. The ore may occur disseminated through the limestone, but generally favours certain beds or horizons, and tends to be located in the neighbourhood of fissures, joints or bedding-planes. The contact of an impervious bed or igneous intrusion is commonly the site of maximum deposition. Deposits of this nature are notoriously irregular, so that their mining is attended with considerable uncertainty, and a thorough knowledge of the geological structure is essential to their successful exploitation. Although they occur almost invariably in limestone or dolomite, they are found also in quartzite and shale, though in such cases the replacement is usually very incomplete.

As in the case of veins, these deposits carry both galena and blende, the latter chiefly in depth. The galena has usually a high silver content, and rich silver ores, such as native silver, argentite and various sulpho-salts, are often a feature of the upper zones. Gold is found also.

These ore bodies are remarkable for an extensive development of oxidized ores, and the zone of oxidation is often deep, yielding large quantities of carbonate and sulphate ores. In many deposits this zone has been the main source of the lead, the primary ore having a preponderance of blende.

Gangue minerals are few; dolomite and allied carbonates are common, and cherty quartz, or "jasperoid," is characteristic. Calcite, barytes, fluorspar and, more rarely, rhodocrosite are found also.

The majority of these deposits have evidently been formed by ascending hydrothermal solutions, though their connection with igneous rocks is not always obvious. Certain ores, however, like those of Missouri, appear to have been derived

from the action of atmospheric waters circulating at shallow depths.

Some of the most remarkable deposits of this nature occur in the Cordilleran region of America, one of the best known being that of Leadville, Colorado, so ably described by Emmons: his opinion of the genesis is not now accepted [1].

Contact deposits.—Metallic deposits occurring at the contacts of intrusive igneous masses are known in many places, and though galena is perhaps the least abundant of all the sulphides occurring in this manner, there are several well-known instances of this character. Such deposits are best developed where the rocks bordering the intrusion are of sedimentary origin, especially limestone; and the ores occur as a metasomatic replacement of the enclosing rock, extending outwards for varying distances from the contact. The deposits may be quite irregular, but where they tend to follow certain horizons are often tabular.

When galena occurs it is invariably accompanied by blende, this mineral, indeed, being of chief importance, and almost always present in deposits of this nature. Pyrite, chalcopyrite and magnetite are common accompaniments. The gangue minerals comprise such typical contact metamorphic varieties as garnet, epidote, actinolite, etc.

The best-known deposit of this class is furnished by the Magdalena Mines, in New Mexico, worked for lead, zinc and silver. By some the celebrated Broken Hill lode is considered a contact deposit, but this is doubtful; formerly it was regarded as a saddle reef [79], [80].

Disseminations.—Ores of lead, usually associated with those of copper and sometimes vanadium, are found disseminated in certain sandstones and shales. The containing rocks are almost invariably of Permian or Triassic age, and form parts of a thick series of strata of lacustrine or shallow-water formation. The ores tend to follow certain beds or horizons in the series, particularly those rich in carbonaceous matter and plant remains, but are by no means confined to these. They often occupy small fissures. Their general mode of occurrence suggests that concentration has taken place after the deposition of the containing strata, and it appears likely that the

ores owe their origin to the leaching effect of atmospheric waters upon the finely disseminated metallic content of rocks accumulated rapidly under arid conditions. They show no connection with any form of igneous activity.

So far as lead is concerned the chief minerals in these deposits are galena and cerussite; with these are usually associated more or less pyrite and various ores of copper; in fact, generally speaking, this class of deposit is of more importance as a source of copper than of lead. Interesting occurrences are various copper and lead vanadates, and the ores frequently contain small amounts of nickel, cobalt, molybdenum and selenium. Gangue minerals are uncommon, and comprise small amounts of barytes, calcite and gypsum.

These deposits are of low grade and can only be profitably mined under favourable conditions. The best-known lead occurrence is in the Triassic sandstone at Commern and Mechernich, near Aix-la-Chapelle.

TENOR OF LEAD ORES

The percentage of metal in crude lead ore naturally varies considerably in different localities, and it is not possible to give any precise details regarding the grade which is necessary for profitable mining, since this will obviously depend upon local conditions and the current price of the metal. The nature of the deposit and the consequent methods of mining it, the character of the ore and the conditions of labour and transport, are all factors which must be taken into consideration.

The mining of argentiferous lead ores has been greatly influenced by the price of silver, and the value of such deposits has been subject to considerable variation with fluctuations in the price of that metal.

In certain deposits, such as some of those of the American Cordilleran region, ore has been mined of sufficiently high grade to be sent direct to the smelters without further treatment, but such bonanzas may be very short-lived, and a high-grade deposit of an irregular and limited character is often less valuable in the aggregate than a low-grade deposit of a persistent and regular nature. Thus in Mis-

souri, low-grade ores, having a recoverable lead content of only 3·5 per cent., are successfully mined with a large and steady output, which amounts to over 5,000,000 tons of crude ore per annum. In the Cœur d'Alene district of Idaho similar conditions prevail, though the ore there is of higher grade. On the other hand, the industries founded on the spectacular deposits of Colorado and Nevada, for example, had a rapid rise and fall, and at the present time these deposits are comparatively unimportant.

Concentration or Dressing of Lead Ores

Only an insignificant amount of lead ore is mined in a sufficiently pure state to need no further treatment, except perhaps hand-picking, before being sent to the smelters. Almost invariably the crude ore has to be crushed and subjected to a process of dressing or concentration for the removal of the waste material, which, in the case of a low-grade ore, may be present in considerable quantity. In the low-grade ores of Missouri, for example, the concentrate obtained amounts only to a little over 5 per cent. of the total ore mined.

The degree of concentration varies considerably in different places according to the nature of the ore and the methods employed, but is seldom, if ever, ideal. A lengthy and very thorough system of dressing operations may result in a finished product of considerable purity, but nevertheless may be uneconomical and attended by considerable loss of lead, so that it becomes undesirable to carry the process to completion. Absolute purity is indeed practically unobtainable.

The dressing of the ore has for its object the removal of not only the gangue minerals, such as quartz, calcite, fluorspar, barytes, etc., but also of any compounds of the base metals—zinc, copper, iron, antimony, etc.—which otherwise have to be removed during smelting and refining. Owing to their comparatively low specific gravity the gangue minerals can usually be effectively separated from the crushed ore by ordinary wet gravity methods, assisted by mechanical devices (jigs, shaking tables, etc.), and the same remark applies to blende, the common associate of galena, when in a moderately coarse state. In cases where the association is of a more

intimate and fine-grained character, as at Broken Hill, N.S.W., the employment of flotation processes becomes needful.

The concentrates produced at various mines differ considerably in grade, for while in some the metallic content is under 50 per cent., in others it is as high as 75 per cent. or over. The average recoverable lead content of the concentrates produced in the United Kingdom may be taken at about the latter amount.

The following tables [4/p. 50] give (1) the tenors of various ores before and after dressing, and (2) analyses of the ore and of the various grades of concentrate produced in south-east Missouri :

Metallic Contents of Various Lead Ores and of the Resulting Concentrates

Locality.	Raw ore per cent. Lead.	Dressed ore.	
		Per cent. Lead.	Oz. silver per ton.
St. Joseph, Missouri	7	70	—
North of England	8·5	70–77	8·00
Bleiberg, Carinthia	8	71	0·05
Przibram, Bohemia	20	37–38	76·50
Freiberg, Saxony	3	18–70	17–88
Tarnowitz, Silesia	6	75·5	13·50
Upper Harz, Prussia	9	64	25·00
Mechernich, Prussia	2	56–60	3–4
Kellogg, Idaho	11	60	30·00

Analyses of the Ore and the Various Concentrates produced in South-East Missouri

—	Ag.(a)	Cu.	Pb.	SiO_2.	Fe.	Al_2O_3.	CaO.	MgO.	Zn.	S.	Ni&Co.
Ore	0·12	0·06	5·7	5·0	4·1	4·9	25·5	14·2	0·8	2·0	—
High-grade concentrate	0·7	0·13	73·2	1·0	3·5	—	2·6	0·8	0·4	15·0	0·05
Medium concentrate	1·3	0·12	68·6	1·4	4·6	—	3·1	1·4	0·8	15·5	0·06
Low-grade concentrate	1·0	0·30	65·8	0·5	3·1	0·5	4·3	2·8	1·7	13·7	—
Flotation slime	—	0·50	45·0	9·6	4·4	3·1	7·5	4·2	4·0	12·3	—
Do. high-grade	3·7	0·05	57·8	6·0	2·7	—	2·2	1·4	9·4	15·5	—
Joplin concentrate	—	—	80·2	1·1	1·0	—	0·4	—	1·7	13·3	—

(*a*) Ounces per ton.

Valuation of Lead Ores

The value of a lead ore to the smelter is dependent upon two main factors, namely, the value of the contained metal and the cost of obtaining it. Broadly speaking, the price paid for an ore will be the value of the net metallic yield minus the total cost of treatment and the profit it is desired to make. But there are other considerations influencing the sale. Thus the quality and quantity of ore offered are important items, and smelters carrying large stocks make a deduction from the market quotation of the metal in order to afford protection against loss due to fluctuation in the market price. In estimating the metallic yield of an ore deductions are made for certain and possible losses during smelting, and, as mentioned above, smelters as a rule cover themselves against unavoidable losses by only paying for 90 per cent. of the lead content of the ore.

The cost of treatment of an ore naturally varies with its character and the methods employed. Carbonate ores, for example, command a higher price than sulphide ores, since the latter must be roasted, a process often involving considerable loss of metal. The nature of the gangue is an all-important factor, and according to the composition of this an ore may be self-fluxing, acid or basic. The first named, requiring little or no fluxes, will naturally command a better price than those to which foreign material has to be added in order to form a desirable slag, as is the case with acid and basic ores. Since most ores are siliceous, basic ores are likely to experience a ready demand.

The price of an ore is affected by the impurities present in it. Substances such as sulphur, arsenic, antimony, zinc, magnesium and aluminium, if present above certain percentages, are charged for, since they cause losses or difficulties during smelting, or may render the lead impure. On the other hand, for silver, gold and copper, when present above certain amounts, payment is made. This is also the case with valuable fluxing agents such as lime and iron, present in suitable form.

The subject of the valuation of lead ores is dealt with in

considerable detail by Hofman [4/pp. 60–66], from whose work much of the information given above is taken.

The average prices of soft pig lead in the United Kingdom, taken from the *Mining Magazine*, for the years 1910 to 1919 inclusive, are given below. Attention may be drawn to the rapid advance in price consequent upon the abnormal conditions brought about by the war. Owing to the acute situation thus created the Government were obliged to assume control of the market and to fix a maximum price.

Year.	Average Price per long ton.	Year.	Average Price per long ton.
	£ s. d.		£ s. d.
1910 . . .	12 19 0	1915 . . .	22 16 10
1911 . . .	13 19 3	1916 . . .	30 19 7
1912 . . .	17 15 10	1917 . . .	30 0 0
1913 . . .	18 6 2	1918 . . .	30 2 8
1914 . . .	18 13 9	1919 . . .	28 3 11

Smelting of Lead Ores [4] [5]

Although in recent years considerable developments and improvements have taken place in the practice of lead smelting, particularly at large central plants, earlier methods are still in vogue locally, and there is a good deal of variation in the methods employed in different places, either in response to local conditions or to the character of the ore treated. Non-argentiferous ores, for example, lend themselves to different treatment from those in which the recovery of silver is of paramount importance. From the smelters' point of view lead ores are classed as sulphide ores (galena) and oxide ores (cerussite, anglesite, etc.), the latter being commonly called carbonate ores.

Lead ore as delivered to the smelters almost invariably contains various impurities, so that its smelting is concerned not merely with the extraction of the lead from its compounds, but also with the removal so far as possible of these extraneous substances. The nature of the impurities has indeed a very considerable influence on the character of the smelting. Thus the presence of sulphur or arsenic necessitates a preliminary roasting, in which considerable loss of

lead and silver may take place by volatilization. Substances like zinc, magnesium and aluminium impair the fusibility of the slag, while arsenic, antimony, zinc, copper, etc., finally render the lead impure, and have to be removed by subsequent refining.

Since the principal ore of lead—galena—is a sulphide, the burning-off of the sulphur is a necessary preliminary to the reduction of the ore to metal, though oxidized ores naturally require no such treatment. In certain methods of smelting desulphurization accompanies reduction, but in the now usual blast furnace practice the elimination of the sulphur so far as possible is usually made by a preliminary roasting. This may be performed in the ordinary way by oxidizing roasting in heaps, kilns or reverberatory furnaces, or by a more recent method of " blast roasting," in which the ore is mixed with lime or gypsum and subjected to an air blast at a comparatively low temperature.

Since the presence of sulphur in the ore materially increases the cost of smelting, it is advisable to reduce it as much as possible ; on the other hand, the loss by volatilization of lead, and of silver in the case of an argentiferous ore, entailed by too much roasting, makes it inadvisable to carry the process to completion. For this reason blast roasting, which is effected at a comparatively low temperature, is preferable to ordinary roasting, as the loss of lead and silver is very much reduced. Owing to the loss of metal entailed in roasting, some smelters, in dealing with certain classes of ore, especially those rich in silver, charge them raw into the furnace.

The presence of sulphur in the blast furnace charge results in the formation of a matte or artificial sulphide of lead, iron and other base metals present. Similarly any arsenic present causes the formation of an artificial arsenide or speiss.

The impurities in the ore are separated during smelting by combining them with other substances into a fusible silicate or slag which, owing to its comparatively low specific gravity, will float on top of the molten lead. The materials commonly employed for this purpose are lime, iron and silica, the composition of the mixture varying with the nature of the impurities present in the ore. Ores are classed as self-fluxing,

acid or basic. The first-named contain a gangue of such composition as to render the addition of further fluxing material unnecessary. Acid ores are those requiring the addition of a base (CaO, FeO, MnO), while to basic ores silica has to be added. The formation of a suitable slag is a most important part of the smelting process, requiring skill and experience, and the necessary fluxes should be readily and cheaply obtainable. Since the addition of fluxes adds to the cost of smelting by reducing the amount of ore in the charge, the smelters at large central establishments, dealing with the produce of several mines, aim at securing ores which will contain, upon mixing, the proper proportions of slag-forming substances without the addition of barren material, though an ideal combination is seldom attainable. A careful selection, however, will considerably curtail the amount of flux to be added to the furnace charge.

The extraction of lead from its ores is based upon two processes, namely:

1. *The Reaction process,* in which a reaction or double decomposition, resulting in the formation of metallic lead and sulphur dioxide, takes place between lead sulphide and lead sulphate or oxide formed by roasting the sulphide; and,

2. *The Reduction process,* in which the liberation of lead from combination is effected by the reducing agency of carbon or of iron.

These processes are not entirely separable in practice, and may be used in combination, though they are not equally applicable to all classes of ore.

Lead smelting may be carried out in reverberatory furnaces, in ore hearths, or in blast furnaces, the last being chiefly in favour at the present time.

Reduction of the ore in reverberatory furnaces is an application of the reaction or double-decomposition process, the lead sulphate and oxide, to which the galena is partially converted by first roasting the charge at a temperature of from 500° C. to 600° C., reacting at a higher temperature, of about 800° C., with the unaltered lead sulphide present, with the liberation of metallic lead and sulphur dioxide. The first operation is conducted at as low a temperature as possible, in

order to secure a maximum formation of sulphate, and the whole process is repeated several times, as all the lead cannot be extracted in one cycle. It is claimed for this method that the ore can be treated raw, i.e. without previous roasting, that few fluxes are required, and that there is little loss by volatilization of lead, and of silver, if present, owing to the low temperature at which the metal is produced. Against these advantages may be set the necessity for a preponderance of galena in the charge, which should contain not less than 60 per cent. of lead and not more than 4 to 5 per cent. of silica. This method is little used at the present time.

Smelting in ore hearths is a combined reaction and reduction process, carbon being used as a reducing agent. Roasting and reduction proceed together. Although this method produces very pure lead, and has the advantages of low fuel consumption and quickness of starting, it is unsatisfactory owing to the heavy volatilization which takes place, and is therefore specially unsuitable for argentiferous ores.

In blast furnace practice the principal reactions which take place are reduction by carbon monoxide and carbon derived from the fuel, and precipitation by iron, though roast reaction also plays some part. The treatment of complex ores can be more satisfactorily carried out by this than by other methods. The separation of the products is effected by the differences in their specific gravities, that of the molten lead being about 10·5, that of the matte varying from 4·5 to 5, while that of a good slag should not exceed 3·6. The charge in the shaft is divisible into zones, according to the range of temperature and the reactions which occur, as follows:

1. The zone of preparatory heating—100° to 400° C.
2. The upper zone of reduction—400° to 700° C.
3. The lower zone of reduction—700° to 900° C.
4. The zone of fusion—900° to 1,200° C.

The slag should be easily fusible at the last temperature, and both it and the matte should be thoroughly liquid in order to ensure a ready separation. For this reason the presence of zinc is to be avoided.

Losses during smelting.—The metal losses which occur during smelting naturally vary with the methods employed. In

blast furnace practice they may range from 4 to 15 per cent., according to the percentage of lead in the ore. Owing to a certain amount of unavoidable loss it is usual for smelters to cover themselves by only paying for 90 per cent. of the lead content of the ore.

Lead fume.—The gases which escape from the furnaces during smelting deposit in their passage through the flues a material known as lead fume, which consists principally of oxide and sulphate of lead. In order to recover as much as possible of the substance, and incidentally to minimize pollution of the atmosphere with noxious gases, the flues are extended as far as possible, in certain cases being as much as 2 or 3 miles long, and various methods have been adopted for arresting the passage of the escaping gases, such as by suspending wire in the flue, by enlarging the flue to such an extent as to reduce the velocity, and by electrical means. Attempts have also been made to condense the gases by filtering them through water, screens of canvas bags, wet faggots, gauze or sawdust. In recent years the Cottrell electrostatic method of precipitating fume from furnace gases has been introduced into certain lead-smelting works with conspicuous success, the efficiency under the best conditions reaching upwards of 90 per cent.

Refining of Lead

During smelting, metallic impurities present in the ore are reduced with the lead, so that the pig lead as obtained from the furnaces is frequently contaminated and unsuitable for many of the purposes for which it is used. This necessitates a subsequent refining process by which the impurities are reduced so that only traces remain. Lead produced in reverberatory furnaces and ore hearths is always purer than that obtained when the ore is treated in the blast furnace, and in some cases may need no refining. The impurities commonly present are antimony, arsenic, bismuth, copper, iron, zinc and silver, and, since their presence renders the lead hard, their removal is known as softening. The recovery of silver, and of gold if present, from argentiferous lead is

known as desilverization, and is the basis of an important industry.

Lead bullion commonly contains from 95 to 98 per cent. of lead, while the best refined lead should contain not less than 99·9 per cent.

Poling of lead.—This simple process is usually performed by the smelters, and is not, strictly speaking, a part of lead refining. It consists merely in agitating the molten metal so as to expose the impurities to the oxidizing action of the air. The oxides so formed remain on the surface as a dross, and can be repeatedly skimmed off. Formerly, poling was performed by thrusting a green pole into the lead, the gases and vapours given off by the wood serving to stir up the melt; but in modern practice a mechanical stirring of the molten metal is carried out by means of steam or compressed air.

This simple process, though far from perfect, serves to remove a considerable amount of impurity, and may be sufficient for the marketing of lead produced from a high-grade ore. In most cases, however, and especially in the case of argentiferous lead which has to be desilverized, a subsequent softening process is carried out by the refiners.

Softening of lead.—This may be accomplished by two processes—liquation and oxidation—both of which are carried out in reverberatory furnaces. The former consists in separating the less fusible impurities by slowly melting the crude lead at a low temperature, while in the latter the metal is heated to a bright red heat with free access of air. In each case the dross which forms on the surface is continually removed to prevent the impurities redissolving into the lead.

These methods effect a considerably higher extraction of the base impurities than poling, and are usually sufficient for the product of non-argentiferous ores, although where special refinement is necessary methods employed for desilverization are used even for such material, the small amount of silver recovered and the enhanced quality of the lead produced justifying the extra cost of treatment. Copper is extracted by zinc in the Parkes process, but the electrolytic process is the only one which offers an improved method of extracting such impurities as antimony, arsenic and bismuth. In any

case, however, where appreciable quantities of these impurities are present a previous softening is always resorted to before desilverization.

Desilverization.—The refining of argentiferous lead has for its primary object the recovery of the precious metals, gold and silver; but at the same time may have the additional advantage of effecting a high degree of extraction of other impurities, thus producing a lead of considerable purity, which can be sold at an enhanced price.

The oldest method of desilverization, but one now little used alone, is the *Cupellation process*, in which the lead is heated in the presence of air with the formation of litharge; the silver having little affinity for oxygen remains in a metallic state after the litharge is run off. This method is very uneconomical, and cupellation is now used commercially only as an auxiliary to the Pattinson and Parkes processes described below. The Parkes process, which makes use of zinc, has of recent years almost entirely replaced the Pattinson, though sometimes the two are run in conjunction, the latter being used to bring the lead to a tolerable richness of about 40 to 60 oz. of silver to the ton.

The Pattinson process is based upon the fact that when low-grade lead bullion is melted and then cooled to its freezing-point, the crystals of lead which separate are much poorer in silver than the original material. By repeated meltings and crystallizations it is possible to obtain a quantity of marketable lead low in silver, and the remaining enriched material can then be cupelled for the recovery of the precious metal. Moreover, the repeated meltings necessary tend to eliminate the other impurities by drossing, and thus to enhance the quality of the market lead. In this process gold separates with the silver, and bismuth shows a similar behaviour, though the separation is not so complete. For most purposes, however, the removal of bismuth in this way is sufficient.

The Luce-Rozan process is a modification of the Pattinson method, wherein steam is used to agitate the melt during crystallization, causing a better and more regular separation of the crystals. It also poles the lead and thus produces a purer product.

Parkes's process makes use of the fact that gold, silver and copper have a greater affinity for zinc than for lead, so that the addition of zinc in proper quantity to the mixture robs the lead of these metals, forming gold-zinc, silver-zinc and copper-zinc alloys. These alloys, being lighter than lead, and having higher melting-points, separate on cooling, and form a scum which can be skimmed off and from which the zinc can be removed by distillation. The quantity of zinc required depends upon the amount of silver contained in the lead, and varies between 1 and 2·5 per cent. For this process the lead, before being desilverized, is softened by liquation or oxidation in a softening furnace.

The Betts process, which is the only really successful method of electrolytic refining, is carried out with an electrolyte of lead fluo-silicate acidified with hydro-fluosilicic acid, and the lead to be refined is cast into sheets for use as anodes and cathodes. During the decomposition of the anode lead, and its redeposition on the cathode, the impurities remain behind in the anode mud, which is collected and refined for their recovery. This process has the great advantage of not only recovering the precious metals, but also of effecting an improved extraction of the base impurities, especially bismuth.

Marketing of Lead

Commercial lead naturally varies somewhat in composition according to the nature of the original ore and the methods adopted for smelting and refining it, but has usually a high degree of purity, and contains only traces of other metals.

The table on the next page gives the percentages of impurities shown by analyses from various sources (quoted from Thorpes's *Dictionary of Chemistry* and Hofman's *Metallurgy of Lead*).

Lead is marketed in three grades: (*a*) *desilverized*, (*b*) *soft*, (*c*) *antimonial* or *hard*. The second term is applied to the product of a non-argentiferous ore which has been refined in the ordinary way, and is less pure than desilverized lead. It may be *ordinary* or *chemical hard*, the latter containing a rather higher percentage of antimony and copper, which,

however, increase its resistance to acids, and make it especially useful for certain purposes in chemical industry.

Antimonial lead is an alloy of lead with about 15 to 30 per cent. of antimony, which is produced as a by-product in desilverizing. Owing to the irregular composition of the material so produced, it is not, however, considered so satisfactory by the users of alloys as when made directly by mixing lead and antimony in the desired proportions.

The purest grade of lead, described as *corroding*, is in great demand for the manufacture of whitelead. It may be produced from very pure ores by ordinary refining, but is usually desilverized lead. Lead refined electrolytically by the Betts process is of this nature.

Properties of Lead

Lead is a bluish-grey metal having a good lustre on freshly-fractured surfaces, though it soon tarnishes on exposure to the atmosphere. When pure it is sufficiently soft to be scratched by the finger-nail, and makes a grey-black streak when rubbed on paper. It is very malleable, but not sufficiently ductile to be drawn into fine wire. Its tenacity is the least among the common metals. It may be easily rolled into sheets or extruded through dies to form piping.

Lead is the heaviest of the base metals, having a specific gravity of 11·37 when solid and of 10·65 when molten (Reich). Its atomic weight is 207·1. It melts at 327·4° C. and boils at 1,525° C. It does not crystallize readily, but when cooled slowly forms small imperfect octahedrons.

On exposure of lead to moist air at ordinary temperatures the suboxide (Pb_2O) is formed ; when melted in contact with air it is converted to monoxide (PbO), the yellow amorphous massicot being first formed at a low red heat, while, at a higher temperature, a bright red heat, this undergoes a molecular change with conversion to crystalline litharge. Steady heating at a temperature of from 300 to 500° C. converts litharge (PbO) into red lead (Pb_3O_4), but this is dissociated at 550° C. At high temperatures the metal combines with silica and is therefore undesirable in furnaces with

siliceous linings. Lead has a great affinity for the noble metals.

Impurities of antimony, arsenic, zinc, magnesium, copper and silver render the metal harder, while tin and bismuth increase its fusibility. The hardness may be increased also by repeated meltings. Antimony, bismuth and copper are said to protect it against the action of sulphuric acid at low temperatures; zinc, on the other hand, renders it more susceptible.

Utilization of Lead [5]

The extreme malleability of lead makes it possible to use this metal for many purposes for which other base metals are unsuitable; thus it is extensively used as sheeting and piping. Sheet lead is made by first casting the metal into plates several inches thick, which are then rolled in a mill to the required thickness. It is largely used as a lining for sinks, acid chambers, vats, etc.; as a roofing material, though now not so extensively as formerly; as plates for electric storage batteries; and as a covering for electric cables. Lead piping, prepared by extruding the metal by hydraulic pressure through a die, is used extensively for conveying drinking-water and gas in dwelling houses, and is also employed in chemical works. For these purposes the lead is usually hardened by the addition of tin and antimony.

The high specific gravity and fusibility of lead render it suitable for the manufacture of bullets and shot, for which purpose it is usual to harden it by the addition of arsenic, antimony or tin, which increases the penetrating power and prevents the shot sticking together when the explosion occurs.

Lead enters into the composition of a large number of alloys, which are considered in the next section (p. 23).

Litharge, or lead monoxide, is largely used in the manufacture of the chrome pigments, as a flux, in the rubber industry, and in glass-making. It is commonly prepared by heating lead in a low reverberatory furnace, with free access of air, at a bright red heat. Appreciable quantities are recovered in the metallurgy of silver. The commercial article frequently contains such impurities as iron, copper, silver

and metallic lead; and if care has not been exercised in regulating the heat during its manufacture, some red lead is usually present. Various qualities of litharge are known commercially by such names as colour-makers' oxide, enamellers' oxide, glass-makers' oxide, potters' oxide, rubber-makers' oxide and varnish-makers' oxide.

Various lead salts are used for industrial purposes. The nitrate is employed in the calico dyeing and printing trades, and for decolorizing sugar solutions; the arsenate is largely used as an insecticide for the protection of fruit trees; while the acetate and carbonate are used for medicinal purposes.

One of the most important applications of lead is in the manufacture of pigments, especially whitelead. Other lead pigments are red lead, orange lead and the lead chromes. Red lead, in addition to its employment as a pigment, is also used by plumbers as a cement for pipe joints; in the manufacture of glass; and in the match-making trade. Owing to its anti-corrosive properties it is very extensively used as a coating for the protection of structural steel.

It is estimated that over 40 per cent. of the lead produced in the United States of America is converted into whitelead, red lead or litharge. The manufacture of lead pigments is dealt with in a later section (pp. 26–32).

Lead Alloys

The table on page 24 gives the percentages of metals contained in various industrial lead alloys.

It will be noticed from this table that tin plays a prominent part in lead alloys, the effect of this metal being to harden the lead without increasing its brittleness or altering its malleability. The two metals will alloy in all proportions; the strongest alloy in tension is composed of 27·5 per cent. of lead and 72·5 per cent. of tin, while the most ductile contains 60 per cent. of lead and 40 per cent. of tin. Alloys with an almost equal percentage of the two metals are the best for ordinary use. Lead-tin alloys are principally used for solder, pewter, organ pipes and toys.

Several alloys are made with antimony. This metal im-

Table showing Compositions of various Lead Alloys

—	Lead.	Copper.	Zinc.	Tin.	Antimony.	Bismuth.	Remarks.
Acid-resisting metal	0·10	83·05	6·00	10·81	—	—	
Ajax plastic bronze	30·00	65·00	—	5·00	—	—	
Babbitt (original)	5·00	4·00	69·00	19·00	3·00	—	
Babbitt (soft)	5·60	3·00	—	84·00	7·40	—	
Bronze (Chinese art)	15·00	74·00	10·00	1·00	—	—	
Camelia metal	14·75	70·20	10·20	4·25	—	—	Also contains 0·55 per cent of iron.
Gurley's metal	2·70	86·50	5·40	5·40	—	—	
Hydraulic bronze	5·00	83·00	5·00	5·00	—	—	Also contains 2 per cent. of nickel.
Magnolia metal	80·00	—	—	4·75	15·00	0·25	
Newton's metal	31·25	—	—	18·75	—	50·00	
Pewter, usual	20·00	—	—	80·00	—	—	
,, French	18·00	—	—	82·00	—	—	Often contain copper.
Phosphor bronze	10·00	80·00	—	10·00	—	—	
Rose's metal	25·00	—	—	25·00	—	50·00	Melts at 93° C.
Solder No. 1	34·00	—	—	66·00	—	—	
,, No. 2 (common)	50·00	—	—	50·00	—	—	Often contain antimony.
,, No. 3	66·00	—	—	34·00	—	—	
Type metal	82·00	—	—	3·00	15·00	—	
Watchmakers' alloy	1·90	58·86	40·22	—	—	—	
Wood's metal	25·00	—	—	12·50	—	50·00	Also contains 12·5 per cent. cadmium: melts at 60·5° C.

parts considerable hardness to lead, but renders it brittle, and where the content is over 24 per cent., the addition of a third metal, usually tin, to counteract this effect is advisable. Battery plates (94 per cent. lead and 6 per cent. antimony), engraving plates (60 per cent. lead and 40 per cent. antimony, with usually a little tin), type metal (82 per cent. lead, 15 per cent. antimony and 3 per cent. tin) and bullets (with 6 per cent. antimony plus small quantities of arsenic) are examples of the application of these alloys. Lead-antimony-tin alloys usually go by the name of *white metal*, or *anti-friction metal*.

Fusible alloys are composed of lead, tin, cadmium and bismuth, in various proportions.

The presence of zinc renders lead too hard for rolling, and also makes it liable to corrosion by acids. Copper, on the other hand, increases its resistance.

The hardening effects of certain metals upon lead have been investigated by Ludwick (*Zeits. anorg. Chem.*, vol. 94 (1916), p. 161), by means of the Brinell method, and some of his results are shown in the annexed table (quoted from Hofman):

Added Metal.	Percentage.	Quenched.	Annealed.	
		Brinell No.	Brinell No	For 2 to 3 hrs. at Deg. C.
Antimony	0·5	7·6– 8·2	6·8– 7·1	
	1	9·8– 9·9	9·5– 9·7	
	2	10·7–10·9	15·1–16·5	230
	4	13·6–13·9	14·0–14·3	
	8	16·8–17·3	15·8–16·1	
Tin	0·5	6·0– 6·4	6·0– 6·4	
	1	6·8– 6·9	6·6– 7·2	270
	2	8·0– 8·1	7·4– 7·9	
	8	10·6–10·9	11·3–11·4	230
Cadmium	0·5	9·1– 9·2	8·9– 9·4	
	1	9·5–10·2	9·7–10·1	270
	2	11·6–12·2	12·6–12·7	
	8	16·7–19·8	14·2–14·5	220
Magnesium	0·5	13·5–15·5	13·8–13·9	
	1	17·9–19·6	16·3–16·4	220
	2	22·3–22·6	19·8–20·9	

Lead Pigments [6] [7]

The lead pigment of chief commercial use is whitelead, while next in importance is red lead. Others are the various lead chromes, orange lead and several of minor importance.

Although the lead pigments have a high density, and possess considerable staining powers, their ready susceptibility to chemical impurities in the air precludes them from ranking as good colours. The presence of soluble sulphides soon causes them to blacken. The lead chromes especially are notorious for their instability. Another great drawback to the use of lead pigments is the danger of poisoning incurred.

WHITELEAD.—This pigment, which is of great antiquity, having been used by the ancients as a cosmetic, is now invariably prepared artificially, and not from the natural lead carbonate, cerussite. The manufactured article is a basic lead carbonate represented by the formula $2PbCO_3,Pb(OH)_2$, which corresponds to about 70 per cent. of carbonate and 30 per cent. of hydrate. Although the different processes of manufacture may result in slight differences of composition, the ratio of carbonate to hydrate should vary but little, since any appreciable alteration in the above proportions seriously affects the quality of the pigment. The percentage composition should approximate to:

Plumbic oxide	PbO	86·32
Carbon dioxide	CO_2	11·36
Water	H_2O	2·32
		100·00 per cent.

Whitelead experiences serious commercial competition from zinc oxide and barytes. The latter material, moreover, is frequently used as an adulterant of whitelead, and considerably lessens the cost of production, though it is claimed that the addition of a small quantity of barytes has a beneficial effect in rendering whitelead less susceptible to the ravages of sulphuretted hydrogen and other soluble sulphides. Its presence may be detected with the aid of dilute nitric acid, which will completely dissolve pure whitelead, but is without action on barium sulphate. Another form of adulteration is

the addition of ultramarine or indigo to mask the yellow tinge in some whiteleads.

For paint-making, whitelead is ground with linseed oil, the amount requisite varying to some extent with the age of the pigment and its mode of manufacture, but on an average 7 per cent. of oil will be required. Whitelead considerably improves with age before grinding.

Various other lead compounds, such as the basic sulphate, used either alone or as a mixture with zinc oxide under the name of leaded-zinc-white, have been introduced, but they do not possess the body of whitelead, and have met with no great measure of success, chiefly because hitherto they have not shown the constancy of composition which is a feature of the long-established brands of whitelead. Sublimed whitelead, which consists principally of basic sulphate, is, however, meeting with an increased demand, and although its colour at first is not equal to that of ordinary whitelead, this improves with age, while that of the latter, of course, deteriorates. Owing to its fineness of grain it finds favour chiefly for mixing with other pigments.

Commercial Preparation of Whitelead.—Several methods are in vogue for the manufacture of whitelead, most of which are based on the old Dutch process of converting lead to basic lead acetate, and treating that with carbon dioxide. The means adopted to secure the reactions differ considerably, however, and in the newer or so-called quick processes are directed towards a speeding-up of the reactions. The principal methods, known as the old Dutch, German, Carter, Matheson and Mild processes, are described below.

In England practically all the whitelead is made by the old Dutch method, though the German Chamber process is used in a few cases. London and Newcastle are the principal places of manufacture, and plants are situated also in Bristol, Sheffield, Chester and Glasgow. English brands of whitelead show great care in manufacture, and are regarded as very pure and of good colour.

In Germany and adjoining countries the Chamber process finds favour, but in France the old Dutch method is still generally used.

In the United States there are large plants operating the Carter, Matheson and Mild processes, but the Dutch method is also employed with modifications.

There is a great tendency towards conservatism among whitelead manufacturers, especially in Europe, so that the old Dutch method is still chiefly in use, though it is claimed that the newer processes produce a purer product and are more economical. The reasons for this attitude are apparently that long-standing practice has resulted in an intimate knowledge and control of the details of the process, thus enabling uniformity of quality to be maintained, and that established brands of whitelead have a ready and secure market against which it is difficult to compete. In the United States, however, the newer processes have made considerable headway, and are operated on a large scale.

Old Dutch process.—This method, which is the oldest, is still responsible for a very large amount of the whitelead made. Modern practice differs but little from that of former days.

For the manufacture of whitelead on the basis of the old Dutch process it is essential that the lead used be of high grade, and in the best brands of corroding lead the impurities do not exceed 0·01 per cent.

Conversion to acetate is effected by means of vinegar or acetic acid, and subsequent carbonation through the agency of horse-manure and spent tan-bark in a state of fermentation. The lead to be treated is cast * into thin gratings or buckles, so as to expose as large a surface as possible to corrosion, and is suspended over the vinegar or acetic acid in earthenware jars, which are arranged on beds of manure and tan. A number of beds, usually ten or twelve, separated by layers of boards, are built one above the other, constituting a stack, and are left thus for from three to four months. The fermentation of the tan-bark not only liberates carbon dioxide, but also raises the temperature sufficiently to vaporize the acid. The product removed from the stack at the expiration of the treatment is crushed and screened to separate the whitelead

* It is essential that cast and not rolled lead be used, since the latter, owing to its hardness, would corrode only with difficulty.

from the cores of unaltered metallic lead. The former is ground in water, and afterwards recovered in settling tanks and dried.

The successful running of this process depends upon the correct tempering of the tan-bark, which should not be too moist or allowed to overheat.

The German Chamber process.—The essential features which distinguish this method from the old Dutch process are the vaporizing of the acid and the introduction of this and carbon dioxide, produced in coke furnaces, into the stack through perforated pipes, so that the actions are under the direct control of the operator. Corrosion is carried out in large closed chambers, in which strips of lead are suspended from racks. It is imperative for the success of this method that the acid be introduced in correct amount and strength, and that a proper temperature be maintained.

The Carter process.—In this and the next described methods, the principles of which are the same as those of the Dutch process, corrosion is accelerated by reducing the lead before treatment to small particles, and by assisting the action with mechanical devices. Moreover, as in the German process, the use of carbon dioxide gas, and the elimination of the decomposing organic matter employed in the old Dutch process, ensures the absence of sulphuretted hydrogen with its attendant blackening effect, and affords, therefore, a product of great whiteness. It is claimed, further, that the percentage of converted lead is from 85 to 90 per cent., as against about 70 per cent. in the old Dutch method.

In the Carter process the lead for treatment is submitted when molten to a jet of steam at high pressure, which breaks it up into a coarse granular powder. This powder is treated in slowly-revolving, long, wooden drums, in which it is sprayed at intervals with dilute acetic acid, and subjected to a current of gas containing 10 per cent. of carbon dioxide. The revolution of the drums causes greater exposure of the material to corrosion, at the same time preventing by abrasion the formation of crusts on the individual grains. Each charge takes roughly twelve days to treat. For the success of this process the lead must not be granulated too fine, and care must

be taken not to add too much water or acid, as otherwise the mass becomes pasty and the reactions are retarded.

The Matheson process.—In this process also, advantage is taken of the more rapid corrosion produced by reducing the lead to small dimensions. For this purpose the molten metal is poured into water, and induced to take a spongy form. It is then converted to acetate in large tanks by contact with acetic acid in the presence of steam and air, being subsequently changed to carbonate by the action of carbon dioxide obtained from coke furnaces. Washing and drying complete the process, the removal of excess water being accomplished by means of filter presses.

Matheson whitelead is remarkably free from metallic lead, but usually contains basic acetate of lead. Although claimed as purer and whiter than that produced by the old Dutch method, it requires more oil for paint-making.

The Mild or Rowley process.—This process, which produces the purest whitelead, is also the cheapest and simplest, involving the use of neither acids nor alkalies, nor of any reagents other than carbon dioxide, air and water. The resulting product is claimed to have a whiteness and density not exceeded by that of any other make of whitelead. The process is based upon the atomization or reduction of the lead into extremely small particles, which is effected by subjecting it, while molten, to the action of high-pressure superheated steam. The particles so formed have a thin coating of lead suboxide, which is very susceptible to further oxidation, and by mechanical agitation of the material with air and water in oxidizing boxes, basic hydroxides are formed. After separation from any metallic lead remaining, the oxidized product is treated with flue gas, containing about 18 per cent. of carbon dioxide, in carbonating tanks. The two processes take about thirty-six hours each, and if carefully conducted result in a product of practically theoretical composition. The absence of impurities renders any further treatment, other than drying, unnecessary after removal of the material from the carbonators; and owing to the small size of the particles the product easily crumbles to a fine powder. The whole process is simple and easily controlled, and possesses the

great advantage of not requiring the highly refined grade of lead used in the Dutch process, any good ordinary grade sufficing. Mild process whitelead is said to be whiter, purer, finer and of a more uniform grain than that produced by the Dutch process.

Red Lead.—This pigment has the same composition as natural red lead or minium (Pb_3O_4), though that mineral is never found in sufficient quantities to be of commercial application. It is of a beautiful scarlet-red colour, but owing to its liability to discoloration, and its tendency to dry quickly, red lead is little used as an oil paint, and is quite inadmissible as a water-colour. Its anti-corrosive properties, however, make it peculiarly desirable as a protective covering for steel work of all kinds. Owing to its great opacity red lead readily lends itself to adulteration, the materials commonly employed for that purpose being barytes and ground glass. The paler and more orange-tinted varieties contain an excess of lead protoxide.

In the usual manufacture of red lead from lead two operations are involved, the metal in the first place being converted into massicot, or yellow lead monoxide. In this operation the lead is heated in a drossing oven, or low reverberatory furnace, with free access of air, the temperature being carefully regulated and maintained slightly above the melting-point of lead, i.e. at about 340° C., as otherwise the oxide formed undergoes a molecular change with conversion to litharge. On the completion of oxidation the charge is allowed to cool, and is then ground and levigated to free it from metallic lead.

The second operation, known as colouring, is performed in a similar manner, but at a lower temperature. As the oxide while hot has a deep purplish colour, only becoming bright red when cold, samples must be withdrawn from the furnace from time to time in order to test the coloration. When oxidation is complete the material is reground, levigated and dried, as before. The successful operation of this process is closely dependent upon a careful control of the temperature during oxidation, as upon this factor depends the molecular state of the oxide and its consequent brightness and depth of colour.

The foregoing method of manufacturing red lead is practically universal, though the *Nitrate process,* which involves the use of sodium nitrate as an oxidizing agent, has met with considerable success, owing to the value of the by-product, nitrite of soda, produced.

ORANGE LEAD.—This is a material of similar composition to red lead, but of different colour, being of a bright orange shade. It is produced by the roasting of whitelead, the material used for this purpose being frequently the waste from the washing and settling tanks.

LEAD CHROMES.—The pigment known as chrome yellow is normally a neutral lead chromate, though the darker, orange and reddish-orange varieties contain also basic lead chromate. The pale-coloured chrome yellows (canary and lemon chromes) have varying percentages of lead sulphate. Chrome yellow is usually made by the reaction of a soluble lead salt, such as the acetate or nitrate, with chromate or bichromate of potassium or sodium. Although lead nitrate produces a richer and stronger-coloured pigment than the acetate, the lower cost of the latter makes it chiefly in favour among colour manufacturers, who prepare it from litharge. For this purpose the litharge should be free from red lead, since this is insoluble in acetic acid.

The various shades of chrome pigments are commonly described as canary yellow, lemon yellow, chrome yellow, chrome orange and American vermilion (Chinese scarlet, Persian red, etc.), the last named being of a scarlet red colour. Chrome greens are mixtures of chrome yellow and various blue pigments.

Like all lead pigments the chromes are distinctly unstable, and readily darken in the presence of soluble sulphides. They have also a tendency to reduction by organic matter.

STATISTICS OF PRODUCTION AND CONSUMPTION OF LEAD

Useful particulars regarding the production and consumption of lead were given for many years previous to the war in the annual volume of *Comparative Statistics* published by the Metallgesellschaft at Frankfort-on-Main, but recent issues

of this publication have not been available in this country. The *Mineral Industry*, published annually in New York, contains much valuable information. For the United States reference may be made to the very complete publication issued annually by the United States Geological Survey under the title of *Mineral Resources of the United States*.

The statistical tables in this monograph have been compiled from various sources by the staff of the Imperial Institute, and give in a ready form for reference a mass of information regarding the production and consumption of lead in the various countries concerned.* Wherever possible the period covered is from 1910 to 1920 inclusive, but figures for the later dates are, in many cases, at present unobtainable, and the tables are therefore incomplete.

It is hoped that these omissions may be rectified in a subsequent edition of this monograph.

The largest producer of lead ore in the world is the United States of America. Next in importance, in the years preceding the war, were Australia, Germany, Spain and Mexico. The output of Mexico declined considerably, however, during the revolution, but has recently been restored. The present position of Germany is naturally uncertain, but in any case her production must have diminished considerably, since the Silesian deposits, from which her main output was derived, were practically closed down after the armistice, and their future ownership is still a matter of doubt.

The productions of the remaining European countries, including the United Kingdom, are much smaller, and in many cases are insufficient to meet the domestic demands, which have therefore to be partly satisfied by imports.

The world's production of dressed lead ore by countries from 1910 to 1918 is shown, as far as information is obtainable, in Table I (page 35), whilst the world's production of metallic lead, for the same period, is shown in Table II (p. 38). In the latter the quantities shown include, in most cases, lead derived from both domestic and imported ores, though there are certain exceptions, as, for example, the United Kingdom and the United States.

* Unless otherwise stated, the figures given are from official sources.

An account of the distribution and production of lead was given by Ingalls in the *Mineral Industry* for 1893 [2]. Diagram I (p. 36) and Diagram II (p. 37) show graphically the outputs of metallic lead of the larger producing and the principal smaller producing countries of the world respectively for the period 1910–1918.

The exports of lead from the chief producing countries are shown in Table III, whilst the imports of lead and of dressed lead ore into the chief countries of consumption are shown in Tables IV and V respectively (p. 39).

According to John E. Orchard, of the United States Bureau of Mines, a recent total production of 1,371,000 short tons of pig lead was financially and politically controlled by different countries as shown below [3]:

—	Financial control (Commercial). Per cent. of total.	Political control (Geographical). Per cent. of total.
United States	49	45
British Empire	17	13
France	13	2
Germany	15	14
Spain	—	11
Austria-Hungary	—	2
All others	6	13
	100	100

Table I

World's Production of Dressed Lead Ore

In metric tons (2,204 lb.)

—	1911.	1912.	1913.	1914.	1915.	1916.	1917.	1918.	1919.
United Kingdom[1]	24,301	25,824	24,679	26,439	21,082	17,386	15,572	15,025	14,094
India[2]	3,270	2,998	4,003	8,927	4,195	9,145	55,657	51,628	—
S. Africa[3, 14]	1,228	5,288	1,382	576	410	3,256	7,936	20,160	27,098
Canada[4]	39,171	54,278	78,020	63,709	66,926	76,698	42,468	68,290	52,462
Australia[5, 11]	411,564	450,676	493,008	359,283	301,802	266,967	250,157	308,470	79,263[6]
Austria-Hungary[11]	24,034	29,163	26,239	—	15,218[7]	—	—	—	—
France[8, 11]	68,107	89,769	83,234	78,687	45,693	97,624	86,374	53,162	10,668[10]
Germany[11]	140,154	142,839	143,799	—	13,583	—	—	—	—
Greece[11]	182,324	175,463	159,348	151,581	104,905	95,418	36,558	—	—
Italy[11]	39,008	41,680	44,654	45,538	41,590	39,460	39,096	37,583	11,937[9]
Portugal[11]	1,185	495	1,046	2,163	—	—	—	—	—
Russia[14]	2,000	2,000	2,000	—	1,632	—	—	—	—
Spain[11]	322,412	284,012	302,678	—	288,201	267,654	253,586	219,638	—
Sweden[11]	2,999	2,877	3,222	3,110	2,671	3,707	3,709	3,170	—
Japan[14]	8,320	7,226	7,200	9,126	9,528	22,686	31,614	21,374	—
China[13, 11]	5,410	4,276	4,066	3,722	57	9,899	13,593	937[12]	137[12]
United States[14]	736,602	753,894	792,068	970,022	974,354	1,081,784	1,055,744[11]	999,236	825,408
Mexico[14]	249,210	219,434	111,060	41,982	84,898	39,940	128,250	197,674	134·760
Peru[14]	4,416	8,100	7,854	6,096	5,392	4,076	2,544	1,264	—
Totals	2,265,765	2,300,292	1,889,560	—	—	—	—	—	—

[1] *Mines and Quarries Report.* [2] *Records of the Geol. Surv. India*—ore only, slags not included.
[3] Rhodesia and Union of S. Africa only.
[4] Mineral Production of Canada, Mines Department—ores shipped, 1910–11 estimated (lead production × 3·63).
[5] New South Wales; Queensland; S. Australia; W. Australia and Tasmania. [6] New South Wales only.
[7] Austria only. [8] Includes Algeria and Tunis. [9] *Can. Weekly Bull.*, Nov. 15, 1920, 23. p. 1457.
[10] Tunis not included. [11] From *Mineral Industry.* [12] From *Chinese Trade Returns* 1919.
[13] Exports. [14] Estimated at double the production of lead for the year.

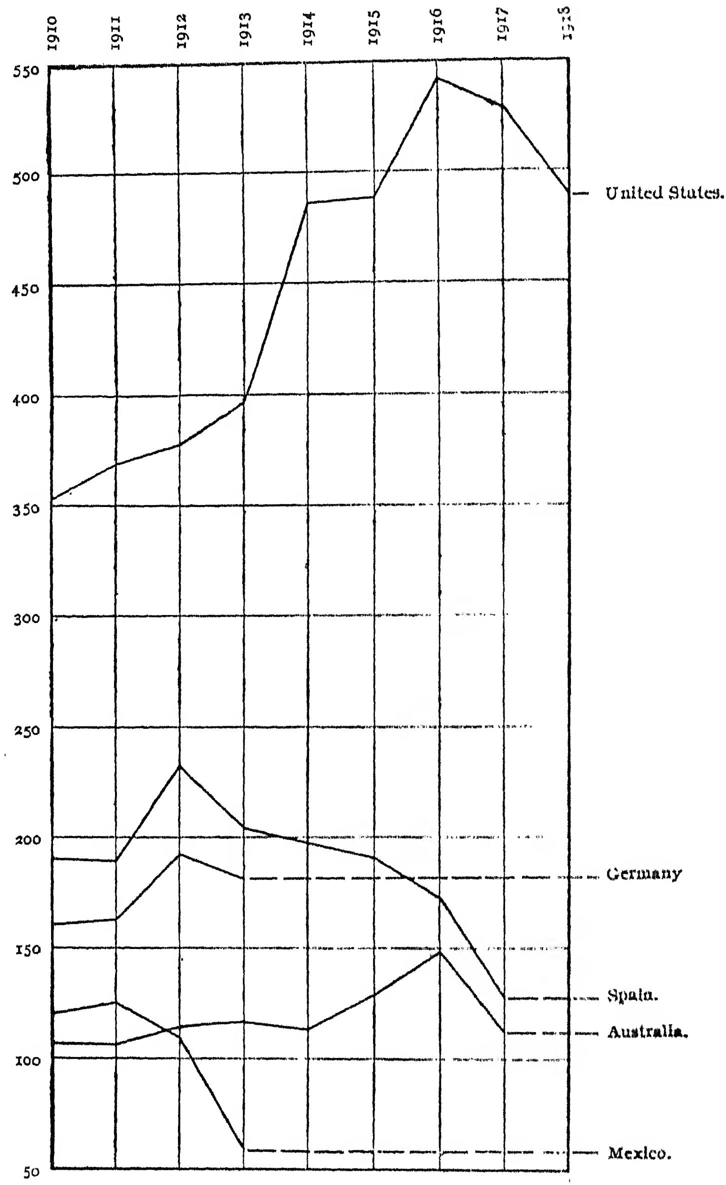


Diagram I.—Showing Annual Productions of Lead of the Larger Producing Countries (Thousands of Metric Tons)

Note.—For some additional information see Table II, p. 38.

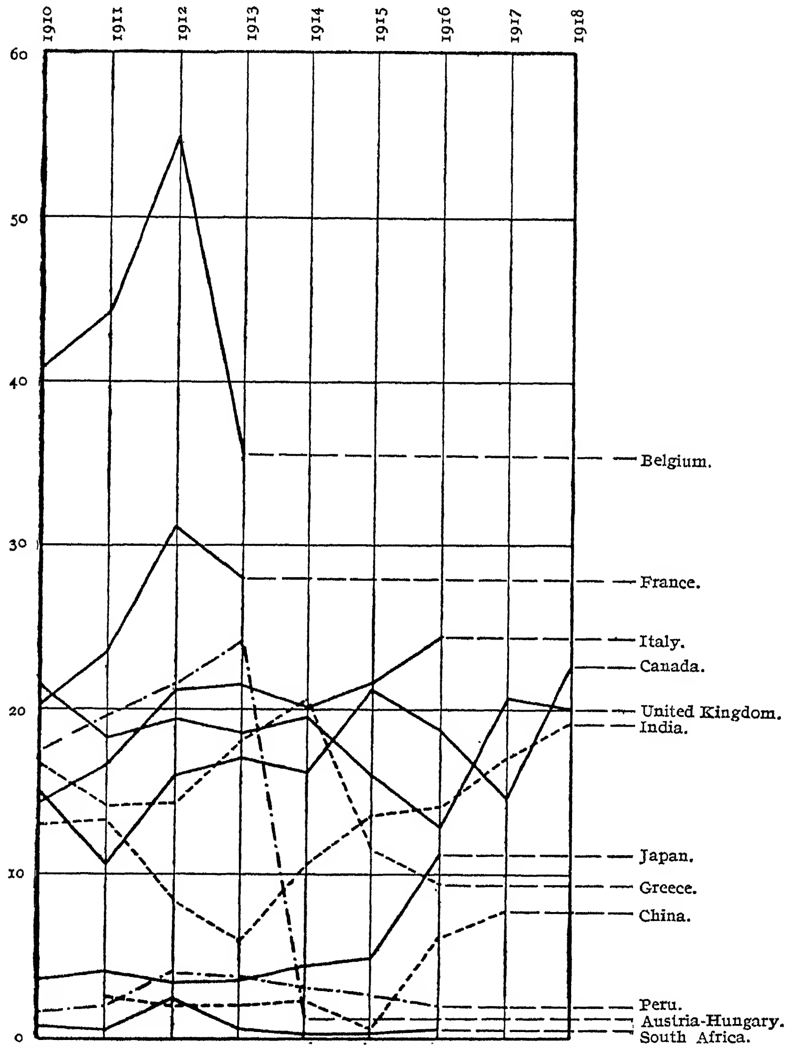


DIAGRAM II.—SHOWING ANNUAL PRODUCTIONS OF LEAD OF THE SMALLER PRODUCING COUNTRIES (THOUSANDS OF METRIC TONS)

Note.—For some additional information see Table II, p. 38.

Table II

World's Production of Lead

In metric tons (2,204 lb.)

—	1911.	1912.	1913.	1914.	1915.	1916.	1917.	1918.	1919.
United Kingdom	18,279	19,473	18,462	19,684	15,767	12,775	11,434	11,088	10,445
India [1]	13,400	8,670	5,999	10,720	13,743	14,015	17,239	19,385	—
South Africa [2]	614	2,644	691	288	205	1,628	3,968	10,080	13,549
Canada [3]	10,791	16,226	17,089	16,487	21,009	18,828	14,780	23,320	19,916
Australia	105,397	113,710	116,000	112,979 [4]	127,816 [4]	146,835 [4]	111,994 [4]	155,105	—
Austria-Hungary	19,680	21,598	23,449	1,368 [5]	14,214	—	—	—	—
Belgium	44,308	54,940	53,590	45,560	16,770	15,560	22,745	20,630	—
France	23,635	31,086	28,817	29,601	14,539	24,276	21,235	12,778	—
Germany	161,287	192,618	181,100	—	—	—	—	—	—
Greece	14,234	14,498	18,309	20,684	11,595	9,424	1,422	—	—
Italy	16,684	21,450	21,674	20,464	21,812	24,362	16,237	18,332	16,530
Portugal [6]	592	247	523	1,081	—	—	—	—	—
Russia	1,000	1,000	1,000	—	—	—	—	—	—
Spain	189,810	232,612	198,829	143,524	171,472	147,407	172,909	169,709	—
Sweden	1,134	1,073	1,235	1,396	1,918	2,076	3,174	2,241	—
Japan	4,160	3,613	3,600	4,563	4,764	11,343	15,807	10,769	—
China [6, 4]	2,716	2,158	2,075	1,861	29	4,950	6,797	469	69
United States	368,301	376,947	396,034	485,011	487,177	540,892	527,872	499,618 [7]	412,704
Mexico	124,605 [4]	109,717 [4]	55,530 [4]	20,991	42,449	19,970	64,125	98,837	67,380
Peru	2,208	4,050	3,927	3,048	2,696	2,038	1,272	632	—
Totals	1,122,835	1,228,330	1,147,933	—	—	—	—	—	—

[1] From *Records of the Geol Surv., India*; includes lead from old slags.

[2] Rhodesia only for 1910, Rhodesia and Union of S. Africa 1911–16, latter from W. Versfeld, *The Base Metal Resources of the Union of S. Africa*, 1919, p. 46.

[3] From Canada Department of Mines. [4] Exports. [5] Hungary only.

[6] Estimated at half the production of lead ore for the year.

[7] From *Mining and Scientific Press*, February 7, 1920 ("Prely. Rept. U.S. Geol. Surv.").

Table III—Summary of Exports of Lead from Chief Producing Countries

In long tons (2,240 lb.)

—	1910.	1911.	1912.	1913.	1914.	1915.	1916.	1917.	1918.
Australia	114,196	100,390	105,222	109,541	111,164	123,021	146,091	110,825	103,586
Canada	8,234	1,428	83	136	122	1,454	936	7,798	7,227
India	13,271	10,177	7,312	3,431	6,509	10,846	10,352	10,569	9,297
United Kingdom	29,525	26,200	29,287	32,186	21,655	24,936	12,960	2,326	59
Belgium	64,847	76,709	77,261	85,829		Not available.			—
Germany	30,526	31,547	37,509	40,704		,,	,,		—
Spain	188,311	200,170	183,295	171,725	150,315	156,512	171,132	152,488	141,222
United States		Quantities not quoted.				97,942	98,350	80,062	85,817

Table IV—Summary of Imports of Lead into Chief Countries of Consumption

(Pig, bars, sheet, etc.)

In long tons (2,240 lb.)

United Kingdom	218,936	213,707	205,375	204,136	224,916	255,977	158,373	147,124	207,932
Canada	5,567	5,904	12,095	11,710	5,640	7,769	23,029	5,829	6,925
Belgium	53,002	82,111	66,945	71,029		Figures not	available.		—
France	63,019	67,861	63,244	75,635	40,307	49,181	62,715	56,916	50,614
Germany	80,231	98,924	92,080	82,435		Figures not	available.		—
Austria-Hungary	16,790	16,961	16,688	12,255		,,	,,		—
Italy	14,438	19,862	15,375	11,309	9,662	17,047	14,127	25,856	12,256
Japan	12,693	15,531	19,037	15,339	15,888	15,448	21,379	16,055	54,344
United States	3,878	2,581	1,516	1,538	565	361	2,336	4,077	8,519

Table V—Summary of Imports of Lead Ore into Chief Countries of Consumption

In long tons (2,240 lb.)

United Kingdom	18,093	17,259	15,720	18,453	28,436	14,062	11,443	8,657	1,502
Austria-Hungary	6,252	1,082	3,188	7,926	—	—	—	—	—
France	28,485	46,579	41,772	39,133	21,430	15,861	40,095	34,464	23,740
Germany	110,348	141,290	120,873	140,699		Figures not	available.	—	—
United States	—	130,701	77,889	48,889	55,807	49,253	88,885	101,736	93,322

CHAPTER II

SOURCES OF SUPPLY OF LEAD ORES

(*a*) BRITISH EMPIRE

As a producer of lead ore for some years past the British Empire has ranked next to the United States—a position entirely due to the large output contributed by Australia. Failing this, the production would have fallen far short of that of Germany.

The deposits of the United Kingdom, at one time the largest producer in the Empire, have been exploited over a very long period, and the output is now considerably less than formerly, though doubtless it could be materially increased by further exploration. A large number of the mines, however, are abandoned, and many must be in an exhausted or impoverished state, so that their future possibilities are a matter of considerable uncertainty. It is not to the United Kingdom, however, that we must look for the large tonnages of the future. As a whole the Empire undoubtedly contains very large resources, many of which are as yet unknown or imperfectly developed. The potentialities of countries like Canada, Australia, British portions of Africa and India must be very considerable, and many important deposits are already known and worked in these countries. Attention may be drawn to the position of Burma with its large reserves and increasing production. The supply of lead ore within the Empire could certainly be relied upon to meet the demand.

EUROPE

United Kingdom

Lead ores are widely distributed in the United Kingdom, but the mining industry has lost its former importance. Lead

mining was most prosperous about the middle of the last century, the maximum annual output of 101,997 tons of dressed ore being reached in 1856, when 353 mines were operating. Since 1870 the output, though subject to annual fluctuation, has shown a general decline, and in 1914 the total production was only 26,013 tons from about sixty mines.

Interesting information regarding the production of lead ore in the United Kingdom is given in the report of the Controller of the Department for the Development of Mineral Resources in the United Kingdom, issued by the Ministry of Munitions in 1918 [8/p. 15]. According to this authority " the total output of dressed lead ore from the United Kingdom for sixty years, dating from 1856 to 1915 inclusive, has amounted to 3,498,279 tons, from which 2,590,845 tons of metal have been obtained, with a value of £46,412,246, to which has to be added the value of silver recovered, which was £5,023,350, making a grand total of £51,435,596.

" This production has been derived from various parts of the United Kingdom in proportions as follows :

	Tons lead metal.
England	1,505,819
Wales	725,055
Scotland	148,617
Ireland	36,211
Isle of Man	175,143
	2,590,845 "

The average metal content in the dressed ore has been about 75 per cent.

Since 1914 the abnormal conditions created by the war have had a serious effect upon the mining industry, and difficulties connected with shortage of labour and machinery have considerably curtailed outputs. On the other hand, the demand created for home ore supplies and the increase in the price of the metal have had the effect of directing attention to many derelict properties which, under normal conditions, were considered worthless, though the extensive nature of the operations necessary in most cases to bring these properties

again to a productive state has prevented any immediate results. Moreover, it is very doubtful whether, so far as lead is concerned, any considerable tonnages are available from many of these sources, for although in some instances increased mining costs combined with a fall in the value of the metal were the main factors in causing abandonment, it cannot be doubted that in others the root cause is to be found in the exhaustion or impoverishment of the deposits. With respect to financial burdens, reference may be made to the heavy pumping charges and to the difficulties of transport with which many mines had to contend. With regard to the former, attention is now being directed to the driving of deep adits in order to effect efficient and cheaper drainage, and such schemes are under construction or consideration in Shropshire, Flintshire and Leadhills. The latter difficulty may be met by means of aerial ropeways, as has been done in Shropshire.

The table on page 43, taken from the Home Office Reports [9], gives the amounts, in long tons, of dressed ore recorded from each of the producing counties from 1915 to 1919 inclusive. It is interesting to compare this table with that for the year 1856 given in the report referred to above [8/p. 15].

The lead ores of the United Kingdom occur in various formations ranging from the Pre-Cambrian to the Triassic, but the commercially important deposits are mostly found in rocks of Palæozoic age. They fall naturally into two groups, namely, veins in the older Palæozoic rocks, and cavity-fillings and metasomatic replacements in the Carboniferous Limestone and associated rocks. The former occur in Cornwall and Devon, Wales, Shropshire, the Lake District, Isle of Man, the Leadhills and Wicklow; while the latter are found over an extensive area in the north of England, in Derbyshire, Flintshire and Denbighshire, and the Mendip Hills.

Of the English counties, Durham has always been the chief producer; in Scotland, the Leadhills district has been responsible for about 95 per cent. of the entire output of that country; while in Ireland the main production has come from the mines in County Wicklow.

Production of Dressed Lead Ore in United Kingdom, in long tons, 1915–19

	1915.	1916.	1917.	1918.	1919.
England :					
Cheshire .	—	—	—	20	—
Cornwall .	9	15	7	12	1
Cumberland .	897	839	720·5	706	1,405
Derbyshire .	3,944	3,232	3,585	2,699	2,930
Durham .	4,123	4,045	3,840	3,369	2,681
Northumberland . .	648	589	429	909	429
Shropshire .	77	32	15	27	12
Westmorland	647	735	683	846	640
Yorkshire .	14	57	42·5	17	8
Wales :					
Cardigan .	1,802	1,163	896	553	391
Carmarthen .	17	26	47	8	—
Carnarvon .	128	184	141	129	51
Denbigh .	—	3	9	19	5
Flint . .	2,721	1,703	824	1,540	1,386
Montgomery .	410	365	85	38	16
Scotland :					
Dumfries .	3,135	2,333	2,056	1,715	1,860
Lanark . .	1,943	1,577	1,773	1,952	1,896
Ireland :					
Armagh. .	—	1	—	—	—
Sligo . .	—	—	4	4	4
Wicklow .	—	—	—	15	20
Isle of Man .	290	208	165	206	129
Totals (*long tons*)	20,744	17,107	15,322	14,784	13,868
,, (*metric tons*)	21,082	17,386	15,572	15,025	14,095

The silver content of the ore shows considerable local variation, the average being about 6 oz. to the ton of concentrate. By far the greatest amount has been yielded by Cornish ores, and important quantities have been recovered also from the ores of Devonshire, the Lake District, Isle of Man, Cardiganshire, North Wales and Derbyshire. In Shropshire and Yorkshire, on the other hand, the galena is practically non-argentiferous.

The accompanying table shows the quantities of silver contained in the ores raised in 1918 [9]:

Table showing quantities of Silver obtainable from Lead Ore produced in United Kingdom during 1918

	Dressed lead ore (in long tons).	Amount of silver content (in oz.).
England :		
Cheshire	20	—
Cornwall	12	—
Cumberland	706	5,975
Derbyshire	2,699	—
Durham	3,369	15,129
Northumberland	909	3,944
Shropshire	27	—
Westmorland	846	8,319
Yorkshire	17	63
Wales :		
Cardigan	553	5,134
Carmarthen	8	36
Carnarvon	129	1,650
Denbigh	19	48
Flint	1,540	10,910
Montgomery	38	72
Scotland :		
Dumfries	1,715	11,147
Lanark	1,952	5,856
Ireland :		
Sligo	4	52
Wicklow	15	90
Isle of Man	206	9,370
Totals	14,784	77,795

Cornwall and Devon [10] [11].—Although the lead mines of this area have shown no appreciable output for the last forty years, the production at one time was considerable. In 1856, for example, there were over fifty producing mines, with a total output of 13,112 tons of ore. In later years the output showed considerable fluctuation, with a general decline, and the industry is now practically extinct [10/p. 647].

The chief undertakings were situated in the neighbourhoods of Ilfracombe (Combe Martin), Okehampton, Tavistock and Beer Alston, in Devon ; and near Callington, Menheniot (Herodsfoot, Wheal Mary Ann [12] etc.), Truro, Helston, Perranzabuloe, Chiverton and Newlyn Downs (East Wheal

Rose, etc.), in Cornwall. In North Cornwall (Endellion, etc.) many of the lead veins yielded ores of antimony.

The lead veins of the south-west of England are contained in Ordovician and Devonian slaty rocks (*killas*), and generally take a north and south direction, practically at right angles to that of the tin-copper lodes, than which they are later in age. Moreover, the typical lead lodes are situated in the killas at some distance from the granite and well away from the tin-bearing localities.

The ore is normally galena, almost always richly argentiferous, ores running from 30 up to 100 oz. of silver to the ton being common. At Beer Alston the proportion of silver, which was usually from 80 to 120 oz. to the ton, rose at one time to 140 oz. The average yield has been over 30 oz. to the ton.

The galena is frequently accompanied by blende, and the veinstones carry quartz, calcite, fluorspar, carbonate and oxide of iron, and occasionally barytes. Not infrequently some copper ore is present. Rich silver ores and many beautiful carbonates, phosphates and arsenates were obtained from the upper parts of the veins.

Although the lead-mining industry of this district is now practically extinct, Collins expresses the opinion [10/p. 526] that there are large tracts of ground in East and North Cornwall where traces of lead may be found in the cross-courses, which, if properly investigated, might prove as rich as any formerly worked.

Mendip Hills [13].—Ores of lead and zinc are found here occupying fissures and cavities in the Carboniferous Limestone and overlying Triassic Dolomitic Conglomerate. The mining history of this area dates back to early times, and the activity of the Romans is evidenced by the pigs of lead, bearing Roman inscriptions, and other relics which have been found. No mining is carried on at the present time, though in recent years the old slag heaps, containing on an average 12 per cent. metallic lead, have been re-treated.

In the neighbourhood of the surface the lead-bearing fissures are said to have carried oxides of iron and manganese, associated with clay, the galena being frequently altered to cerus-

site. Very little blende was met with, though important deposits of calamine have been worked in the Dolomitic Conglomerate. It is most probable that deposits of blende await discovery at greater depth.

This locality is notable for the occurrence of the rare oxy-chloride of lead, *mendipite*, and, as at Laurium in Greece, various secondary lead minerals occur in the old slag heaps, among which *leadhillite*, the sulpho-carbonate, deserves notice [14].

As operations in this area seem to have been of a shallow nature only, it would appear that the district deserves renewed attention in the light of modern methods.

Derbyshire [15].—The lead deposits of this county occur in the Carboniferous Limestone as cavity fillings and meta-somatic replacements. The various forms assumed by the ore bodies are recognized by the miners under such terms as *rakes*, *scrins*, *flats* and *pipes*, though the different types are not always distinctly separable, and they usually occur in association. Rakes, or rake-veins, are more or less vertical deposits in enlarged joints or faults, while similar occurrences in small cracks or fissures are recognized as scrins. Flats are deposits in horizontal cavities formed along bedding planes; one or more generally occur in association with a fissure filling, giving rise to a pipe. The term *pocket* is sometimes applied to deposits in chamber-like cavities on the side of a rake.

The ores are confined almost entirely to the Carboniferous Limestone, very few veins extending into the overlying Yore-dale Shales. The deposits are said to be most productive in the upper part of the limestone, and it has long been an estab-lished fact that on passing downwards into the sheets of igneous rock (*toadstones*) which are intercalated with the limestone, they become impoverished or barren.

The galena is accompanied by blende, and oxidized pro-ducts of both these ores occur. It is said that blende occurs more particularly in association with the harder beds of limestone, and that it increases with depth. Calcite, fluorspar and barytes are the gangue minerals, quartz being almost absent. Derbyshire is famed for the massive, fibrous and

concentric variety of fluorspar known as *Blue-john*, which has been obtained exclusively from the Treak Cliff Mine, near Castleton. Much of the barytes is the earthy variety known as *cawk*. Many of the veins show a beautiful banding or crustification, the ores occurring in marginal or central layers, or alternating with the other minerals. In the flats, especially, ribs of pure, massive galena are found.

Although lead mining in Derbyshire was formerly an important industry it has now declined considerably, and for several years past only one mine, Mill Close, in Darley Dale, has been in continuous operation for the production of lead ore [16]. This mine, which was reopened in 1859 after a period of idleness, was flooded from 1875 to 1877, but started operations again in 1883, when an entirely new dressing plant was erected, and its output has been fairly regular since.* The lead concentrate produced carries about 80 per cent. of metal, and the mine yields also a small quantity of zinc ore annually [15]. The production in 1916 was 2,963 tons of lead concentrate, and 196 tons of zinc concentrate.

Some of the Derbyshire mines are now worked for fluorspar and, to a less extent, for barytes. An account of the fluorspar occurrences is given by Wedd & Drabble [17], in whose paper will be found a useful map showing the distribution of the Derbyshire mineral veins.

The Pennine Region [18].—This tract of country, comprising portions of the counties of Northumberland, Durham, Cumberland, Westmorland and Yorkshire, is characterized by an extensive outcrop of Carboniferous Limestone, in which a widespread deposition of lead ore has taken place. The Carboniferous Limestone Series consists of a group of strata composed chiefly of an alternation of limestones, cherts, sandstones and shales, and the different members exert a very considerable influence upon the productivity of the veins. The ore occurs chiefly in the limestones and cherts, the sandstones rarely affording any regular supply, while the shales are almost invariably poor or barren. In places the deposits extend into the overlying Millstone Grit, as at Grassington,

* Quite recently the working of this mine has been interrupted by labour troubles.

but the vertical extent of the productive ground is subject to great local variation.

The ore bodies are chiefly infillings of fissures, very frequently faults, but there is also a good deal of metasomatic replacement of the limestones, particularly at the junction with some impervious bed. Deposits in which the ore occurs as irregular sheets, roughly parallel to the stratification of the enclosing strata, are known as flats, and have been an important source of ore supply.

The galena, which on the whole is not notably argentiferous, though locally so, is commonly accompanied by blende, but the relative occurrence of the two ores is subject to considerable variation. The latter is met with more especially in depth, so that mines formerly worked exclusively for lead, such as those near Alston, are now producers of zinc. The gangue minerals, which comprise chiefly calcite, fluorspar and barytes, show a local distribution. Thus, while in Weardale the veins carry fluorspar, in Teesdale, immediately to the south, the corresponding material is barytes. These minerals are now frequent objects of exploration.

The chief mining centres are situated in the neighbourhood of Hexham, Northumberland; Upper Teesdale and Weardale, Durham [19]; Alston Moor, Cumberland [20] [21]; Brough and Dufton Fell, Westmorland; and Upper Swaledale, Arkendale and Wensleydale, Yorkshire; but most of the mines are now derelict, though in past years they yielded a very large part of the British output of lead ore. Several of the workings have been re-opened from time to time and equipped with modern machinery, but often with little success, although one or two have become important zinc producers, notably the Nenthead Mine, near Alston, worked by the Vieille Montagne Company. Some of the mines are now worked for barytes, which is a common gangue mineral of the veins, but was formerly disregarded or thrown to waste, having at that time little value. In recent years most of the lead production has come from Weardale, where a group of mines are operated by the Weardale Lead Company. This company, which was formed in 1883, and reconstructed in 1900, produced between 1884 and 1916, 117,222 tons of lead

ore and, since 1898, 132,327 tons of fluorspar. Operations have been mainly conducted at the Boltsburn Mine [19].

Although it cannot be doubted that some of these mines still contain important reserves of lead ore, and more especially of zinc ore, the isolated situation of many of them, remote from railways, renders the question of transport a problem for serious consideration in connection with their working. In many cases the most satisfactory solution would appear to be the erection of aerial ropeways.

The Lake District.—The older Palæozoic rocks of the Lake District, comprising portions of Cumberland and Westmorland, contain many veins of lead ore, though at the present time less mining than formerly is carried on. The chief mines are located in the Caldbeck Fells (Roughtengill, etc.) and near Keswick (Threlkeld, Thornthwaite, Force Crag, etc.) in Cumberland, and in the neighbourhood of Ullswater (Greenside, etc.) in Westmorland. Some of the properties are now worked for barytes.

The galena, which contains appreciable quantities of silver, ores carrying from 25 to 35 oz. to the ton having been obtained, though the average is less, is commonly associated with blende and with more or less copper ore (chalcopyrite). Oxidized ores (carbonates, sulphates, phosphates and arsenates) have been frequent, and the district is noted for several rare species, such as *linarite, leadhillite, caledonite,* etc.

One of the most productive mines in this district has been Roughtengill, extensively worked for lead, zinc and copper. Interesting and useful particulars of this and the other mines of the Lake District are given by Postlethwaite [22].

Shropshire.—In the old lead-mining region of Shropshire and adjacent portions of Montgomeryshire, which has its centre in Shelve, lead-bearing veins are contained in Ordovician strata, and trend roughly east and west or north-west and south-east. The ore-bearing horizon is practically limited to the Mytton Grits, which immediately overlie the Stiperstones Quartzite, at the base of the Ordovician sequence, and are bounded above by the Hope Shales. Blende accompanies the galena in many of the veins, and increases with depth. In those veins which have a north-westerly trend the gangue is

calcite and galena occurs up to the surface, while the majority of the easterly and westerly veins have a barytes capping. Oxidized ores are rare, and the galena contains no appreciable amount of silver.

There are numerous mines in the district, the majority of which are abandoned and flooded, but during the last few years a considerable portion of the area has been acquired by the Shropshire Mines, Limited, which has undertaken the construction of a deep drainage adit, the Leigh level, for the purpose of unwatering a large group of the mines. It is hoped that this, when completed, will enable the properties to be worked to considerably greater advantage than formerly.

The output of lead ore for this district reached a maximum in 1875, when 7,932 tons of concentrate were produced, chiefly from the Roman Gravels, Tankerville and Snailbeach Mines, since when the production has more or less steadily decreased, and at the present time there is only one mine (The Bog) from which any lead ore is obtained. By far the largest production has come from Snailbeach Mine, which, until recent years, maintained a continuous yearly output, but is now flooded. The mineral statistics of the district show that many of the properties have had a chequered history, and the productions of even the best mines rapidly declined before the cessation of operations. Subsequent re-opening of some of them does not appear to have met with any substantial success. It is said that a fall in the price of lead, combined with heavy pumping and transport costs, militated against successful operations, and as the latter items have now been seriously taken in hand by the present company, the former by means of a deep adit and the latter by the erection of an aerial ropeway, it is hoped that the district may again become an important producer of ore.

Although lead mining has so seriously declined, the production of barytes, on the other hand, has very considerably increased. This material is obtained largely from the old workings or adjacent veins, above water-level. It forms a gangue or capping to many of the veins, and was formerly largely disregarded, but now commands a ready sale.

Lead mining in this district dates back to Roman times, as evidenced by the pigs of lead and other remains which have been found. An account of the geological and mining features of the area was given by Morton in 1869 [23].

Alderley Edge.—Some of the Triassic sandstones in the neighbourhood of Macclesfield, Cheshire, noted more especially for their ores of copper, have likewise yielded lead ore in the form of cerussite, galena, pyromorphite and vanadinite. Although attempts to work these rocks for their lead content have met with no substantial success, the deposits bear a close similarity to those which have been extensively exploited near Mechernich and Commern, in Germany, described hereafter (p. 88).

A rare vanadate of lead and copper from this locality has been described under the name of *mottramite* [24].

Flintshire and Denbighshire.—The Carboniferous rocks found in these counties contain a number of veins carrying ores of lead and zinc which have been of considerable commercial importance, the most productive undertakings being the Halkyn Mines near Holywell, in Flintshire, and the Minera Mine near Wrexham, in Denbighshire. The latter, now shut down, at one time the most productive lead mine in Britain, became in its later years chiefly a producer of zinc ore.

The Halkyn deposits occur for the most part in faults traversing the Carboniferous Limestone and overlying chert beds of the Millstone Grit. There are two well-marked sets of veins, and it is interesting to note that those which have an east and west trend, and appear to be older, carry both argentiferous galena and blende, while the later, north and south veins, or cross courses, contain practically no blende, and the galena is much poorer in silver. The veins are said to have been most productive below the pyritiferous Holywell shales, which evidently exerted a control upon the deposition of the ore. Their characters and mode of occurrence are fully described by Aubrey Strahan in the Geological Survey Memoirs of the district [25] [26]. In the upper workings carbonate ores (cerussite and calamine) were abundant.

The mines of the Halkyn district are drained by a deep adit, about four miles long, which, at the time it was con-

structed, gave a new lease of life to the district, and enabled the mines, which one after another had been compelled to close down owing to excessive pumping charges, to recommence operations. Subsequently, however, the workings extended below the adit level, and the same difficulty again caused abandonment of the properties. A new adit, about six miles long, to drain the district to a depth of 200 ft. above sea-level, was being driven by the Halkyn District Mines Drainage Co., but the work is now stopped for financial reasons [82/pp. 15–17].

Carnarvonshire, etc.—Veins carrying ores of lead and zinc occur in the older Palæozoic rocks of Carnarvonshire, as at Bettws-y-coed, Llanrwst, Trefriw and Trecastell, in the Conway Valley. Only a few mines on these deposits are in operation, however, and with little success, the total yearly output of lead ore for the last few years averaging only a few hundred tons. The principal property, Trecastell Mine, produced in 1916, 132 tons of dressed lead ore and 105 tons of zinc ore.

Lead ore is found in the well-known copper deposit of Parys Mountain in Anglesey, though the occurrence is not of much commercial interest. Occasionally small quantities of lead ore were produced, and also zinc ore, from this source. This is the original locality for anglesite, which is said to have occurred here at one time in some abundance.

Central Wales.—Lead veins, traversing slaty Palæozoic rocks, occur over a large part of Central Wales, principally in the county of Cardiganshire, and were at one time the scene of great mining activity. The deposits have been fully described by Warrington Smyth [27]. The veins trend roughly north of east and south of west, but their directions are subject to much local variation. They carry both galena and blende, the latter, which increases with depth, being at the present time the chief ore worked. The fissure fillings are largely composed of brecciated country rock cemented by quartz and calcite, in which the ore occurs irregularly distributed. Calcite is less abundant than quartz, but its presence is said to favour the occurrence of ore. Barytes is uncommon, while fluorspar is said to be absent. In some places pyrite

is very abundant. The silver content of the galena is, on the average, not high, though in some cases it reached as much as 30 oz. to the ton.

Only a few mines are now being worked in this area, and many of the largest and most important properties are derelict. The majority of them are remotely situated and difficult of access. The well-known Van Mine, near Llanidloes in Montgomeryshire [28], on the eastern edge of the district, has continued operations up to the present time, and produced in 1916, 326 tons of dressed lead ore and 18 tons of zinc ore.

South Wales.—Occurrences of galena in the Carboniferous and overlying Triassic rocks of the South Wales coalfield have been frequently noted, though so far they have proved of no commercial importance, attempts to mine them having been unsuccessful.

Isle of Man.—The lead ores of this region occur in veins traversing Cambrian slates and associated granite. The galena, which is richly argentiferous, is accompanied by a considerable amount of blende, and the chief veinstones are quartz and calcite. The occurrence of *plumosite,* an antimonial lead sulphide, is noteworthy.

The lead production of the Isle of Man has been very considerable, the main output coming from the famous Foxdale and Great Laxey Mines. At the present time the former property is abandoned, while the latter has become chiefly a zinc producer. In 1916 this mine produced 208 tons of lead ore and 865 tons of zinc ore.

At Foxdale the main lode was traced for a distance of between two and three miles, and in places was as much as 40 feet in width. Mining operations extended to a depth of about 2,000 ft. At Laxey the deposit carried a fair quantity of copper sulphides, and at one time copper ore was produced.

The ore deposits of this region have been fully described by G. W. Lamplugh [29].

Leadhills and Wanlockhead.—These two groups of mines, which adjoin one another, the former being in Lanarkshire and the latter in Dumfriesshire, operate upon a system of veins which extend over a tract of country measuring roughly two miles north and south and three miles east and west.

Mining operations have been continuous for over 200 years, and the district has yielded about 95 per cent. of the entire lead output of Scotland.

The veins occur in slaty rocks of Ordovician age, and carry both galena and blende, the latter having been found so far only in subordinate quantity. The chief gangue mineral is calcite, though barytes occurs also. The upper portions of the veins formerly yielded a great variety of oxidized products, for which this district is famous, including several rare basic sulphates and sulpho-carbonates, only occasionally found in Britain.

Cerussite, anglesite and pyromorphite have all been raised as ores at one time or another.

An interesting account of the mining and history of the district, with a map of the veins, has been given by John Mitchell [30], from whose description the following particulars are taken. For the last fifty-two years, up to the end of 1917, Leadhills produced 88,796 tons of dressed lead ore, the output for the last ten years of that period being 18,162 tons, while during the same time Wanlockhead produced 91,509 tons of lead ore and 8,654 tons of blende, the corresponding figures for the last ten years being 25,324 and 6,513 respectively. The returns before the period given are difficult to obtain. In 1914 the crude ore of Leadhills yielded 10 per cent. of lead concentrate, while that of Wanlockhead gave 4·95 per cent. of lead concentrate and 1·62 per cent. of zinc concentrate.

Owing to difficulties experienced with the water, and the heavy pumping expenses necessary, a scheme for unwatering the mines by means of a deep adit has been under consideration. This adit, starting from Enterkinfoot, and having a total distance of about 7 miles, would intersect the veins at a depth of nearly 1,000 ft., and would take from five to six years to complete. It is anticipated that such an undertaking will not only render possible the re-opening of some of the mines, but will at the same time prove a large extent of unexplored ground [8/p. 34].

Strontian (Argyllshire).—The lead ores of this neighbourhood, which occur in veins traversing gneissic rocks near a granite outcrop, were first mined at the beginning of the

eighteenth century, and operations were continued for about 150 years. The locality is notable for having yielded the mineral *strontianite*, in which strontium was first discovered.

The galena is associated with calcite and barytes, and interesting occurrences are *strontianite* and *celestine*, and the secondary barium- and strontium-bearing zeolites, *harmotome* and *brewsterite*.

Although no lead is now raised at Strontian attention has recently been directed to the locality as a possible source of barytes. According to the *Geological Survey* there is a considerable quantity of galena lying in some of the spoil heaps [31/p. 88].

Ireland.—About 80 per cent. of the lead ore production of Ireland has come from the Luganure Mines in County Wicklow, which were operating up to about the year 1892. Since then the output of lead ore from Ireland has practically ceased [8/p. 15]. The veins from which this ore was derived occur in a belt of mineralized granite and slate which stretches southward into Wexford. Lead ores occur principally in the northern portion of this tract, in Glendasane, Glenmalure, and Glendalough, while to the south copper ore is abundant and was long worked at the well-known mines of the Vale of Avoca. The mines of this region were described by Warrington Smyth in 1853 [32].

Ores of lead have occasionally been mined in the Carboniferous Limestone and older rocks of other parts of Ireland, as in Galway, Sligo, Clare, etc., but the output has never been large.

Consumption of Lead in the United Kingdom

The amount of lead consumed by any particular country in a given period may be roughly gauged by subtracting the amount of exports from the sum of the domestic production and imports, thus:

Consumption = (Domestic Production + Imports) − Exports.

Such a computation, however, takes no account of any unused stocks remaining in the country, and in any case is only approximate. A reliable estimation of the amount of

lead consumed by a country such as, for example, the United Kingdom, in which imports and exports show considerable overlapping, is a by no means simple matter, on account of the many factors which have to be taken into consideration. Thus, the lead stocks of the country may be derived partly from domestic ores, partly from imported ores and partly from metal imported as such; and in the case of the former two it is necessary to know the grade of concentrate—a very variable factor—before making any reliable estimation of the metallic yield. Against these items one has to consider, in the matter of exports, the lead contained in domestic ores exported as such, and lead derived both from domestic and imported ores and exported as metal. The question may be further complicated by re-export of material.

In the case of the United Kingdom the computation for 1914, the last year for which normal statistics are available, may be approximately made as follows, all quantities being given in long tons:

	Tons.	Tons metal.
Domestic production of ore (say 75% metal)	= 26,013 =	19,510
Imports of lead ore (say 60% metal) .	= 28,436 =	17,062
Imports of metallic lead . . .		= 224,916
Total imports of metal . .		= 241,978
Exports of lead ore (say 75% metal) .	= 3,715 =	2,786
Exports of pig lead . . .		= 21,655
Total exports of metal . .		= 24,441

The consumption was therefore:

(19,510 + 241,978) − 24,441 = 237,047 long tons.

In this computation the metallic content of the domestic ores is taken at 75 per cent., since this has been the average grade of the concentrates produced for many years past. On the other hand, the grade of imported concentrates has been put at only 60 per cent., as these are likely to vary within fairly wide limits, and some may be as low as 50 per cent. It is further assumed that all exported ore is of domestic origin, as seems most likely.

It will be noticed to what a large extent the United Kingdom is dependent upon imported material, its own deposits, now

largely abandoned or impoverished, being quite inadequate to supply the demand, even were all the ore produced retained in the country. In fact, the amount of metal obtainable from domestic ores is somewhat less than that exported, so that it may be said that under existing conditions we are entirely dependent upon imported material for domestic consumption.

The production of dressed lead ore in the United Kingdom for the years 1915 to 1919 inclusive is given in the table on p. 43. Tables Nos. VI, VII, VIII, IX, on pages 58–60, show the quantities and values of recent exports and imports of dressed lead ore and of lead, respectively, and the various countries of reception and origin.

A perusal of these tables brings out the serious effect of the war both on exports and imports, the figures for that period showing very considerable decreases. The exports, especially, reflect the condition of affairs. Thus, the closing of the Belgian and German markets, to which previously the bulk of the exported ore was consigned, reduced the exports of lead ore to insignificance. Similarly a marked decline is observable in the quantities of pig lead exported, though in this case the situation seems to have arisen from the lack of shipping rather than from the closing of the markets. To the producer, however, the position was more than compensated for by the increased home demand, which, in point of fact, exceeded the supply, and resulted in a rapid advance of price, as will be seen from the table on p. 12.

Previous to the war the bulk of the pig lead manufactured in the United Kingdom found its way to Canada, France and Russia, but during hostilities these markets fell away. During that period Canada imported large quantities from the United States (see Table XI). The exports to France practically ceased during 1916–17, and the present position as regards Russia is naturally very uncertain.

The imports of dressed lead ore into the United Kingdom have been derived, on an average, in about equal proportions from the British Empire and from foreign countries, the main contributing country in the former case being Australia, while in the latter instance the largest supply has come from South America. During the war these sources of supply were, on

Table VI

Exports of Dressed Lead Ore from United Kingdom *

In long tons (2,240 lb.)

To	1911.	1912.	1913.	1914.	1915.	1916.	1917.	1918.	1919.
Belgium . .	1,309	1,604	2,649	2,549	—	—	—	—	—
Germany . .	1,248	492	532	945	—	—	—	—	—
Other countries .	283	316	377	221	86	152	210	18	478
Totals . .	2,840	2,412	3,558	3,715	86	152	210	18	478

* Annual Statement of Trade of United Kingdom.

Table VII

Exports of Pig Lead and Manufactures from United Kingdom *

In long tons (2,240 lb.)

	1915.	1916.	1917.	1918.	1919.	1920.‡
To British countries:						
India . . .	4,723	4,360	2,641	1,866	2,947	4,265
Ceylon . . .	1,265	836	338	217	361	
British East Indies .	2,162	709	39	2	751	—
Canada . . .	1,019	927	155	1	382	5,207
South Africa . .	1,447	1,010	372	101	145	181
Other British countries	1,337	2,160	352	178	1,111	—
Totals . . .	11,953	10,002	3,807	2,365	5,607	9,653
To foreign countries:						
France . .	4,243	972	5	29	1,810	1,370
Russia . . .	12,024	10,675	2,398	—	382	563
Sweden . . .	1,618	688	149	2	1,536	1,960
Denmark . . .	2,098	562	26	20	504	—
China . . .	227	256	189	11	2,210†	737†
Japan . . .	762	893	741	727	5,647	1,381
Java	1,969	2,493	1,592	1,676	1,609	—
South America . .	1,592	831	57	5	678	—
Other foreign countries	3,907	1,038	310	83	4,279	12,310
Totals . . .	28,440	18,408	5,467	2,553	18,655	18,321
Grand totals . .	40,393	28,410	9,364	4,918	24,352	27,974

* From Annual Statements of Trade of United Kingdom, and monthly trade and navigation of U.K.

† Including Hong Kong. ‡ Nine months only.

Table VIII

Imports of Dressed Lead Ore into United Kingdom *

In long tons (2,240 lb.)

	1912.	1913.	1914.	1915.	1916.	1917.	1918.	1919.
From British countries :								
Australia	3,863	5,032	15,234	6,641	4,962	—	421	13
Canada	223	114	101	113	102	—	—	—
India †	—	115	9	4	1	2,050	14	—
Other British countries	859	1,402	951	510	140	1,253	5	37
Totals British countries	4,945	6,663	16,295	7,268	5,205	3,303	440	50
From foreign countries :								
Argentina	370	69	342	1,689	1,614	1,688	—	609
Belgium	180	132	268	—	—	—	—	—
Chile	92	188	645	448	167	580	727	360
Colombia	1,152	885	733	36	—	—	—	490
France	1,728	1,088	121	37	76	107	—	1
Germany	1,023	621	565	—	—	—	—	—
Netherlands	421	541	375	—	11	—	—	—
Peru	4,674	4,015	4,398	2,904	3,500	2,180	108	712
Spain	134	8	127	145	47	138	—	1,064
Tunis	550	3,504	3,873	—	—	—	—	—
Other foreign countries	451	739	694	1,535	823	661	227	1,149
Totals foreign countries	10,775	11,790	12,141	6,794	6,238	5,354	1,062	4,385
Grand totals	15,720	18,453	28,436	14,062	11,443	8,657	1,502	4,435

* Annual Statement of Trade of United Kingdom.

† Included in "other British countries" prior to 1913.

Table IX

Imports of Lead (Pig and Sheet) into United Kingdom *

In long tons (2,240 lb.)

	1911.	1912.	1913.	1914.	1915.	1916.	1917.	1918.	1919.
From British countries :									
Australia	56,548	60,292	72,252	68,519	83,221	76,649	93,654	85,280	93,276
India	11,277	5,723	3,064	3,708	6,753	2,089	1,720	2,338	952
Other British countries	152	635	162	44	290	436	468	5,185	18,384
Totals British countries	67,977	66,650	75,478	72,271	90,264	79,174	95,842	92,803	112,612
From foreign countries :									
Belgium	1,055	2,929	4,090	7,642	—	—	—	—	—
France	49	6,994	1,568	8	65	16	—	—	—
Germany	2,582	2,294	2,733	2,273	—	—	—	—	—
Greece	1,310	—	1,767	11,111	14,036	7,312	—	1,253	5,700
Italy	—	—	—	1	—	—	3,506	—	—
Mexico	20,219	17,757	10,380	1,735	250	—	—	—	2,114
Spain	75,798	75,466	77,596	92,145	99,155	62,576	36,268	49,977	39,502
United States	39,498	28,279	24,155	31,048	52,058	7,467	10,084	61,576	53,008
Other foreign countries	5,219	5,006	6,369	6,682	149	1,828	1,424	2,323	4,674
Totals foreign countries	145,730	138,725	128,658	152,645	165,713	79,199	51,282	115,129	104,998
Grand totals	213,707	205,375	204,136	224,916	255,977	158,373	147,124	207,932	217,610

* Annual Statement of Trade of United Kingdom.

the whole, maintained, the drop in the total amount of imports being due chiefly to the failure of the European supplies, notably those of Germany, France, Belgium and the Netherlands. The large increase during 1917 of the quantity of ore imported from India is an important feature.

As regards imports of metallic lead, by far the largest amount obtained within the Empire has come from Australia, the tonnages during latter years having exceeded those from any other country. In fact, during 1917, the quantity was greater than that from all other countries combined. Previously our largest imports came from Spain, but the tonnages from this source declined considerably during 1916–17. The failure of supplies from Belgium, Germany and France during the war was partially balanced by the increased amounts received from Greece and Italy.

ASIA

India

Galena occurs in many parts of India ; but the only deposits being worked on a large scale at present are those of Bawdwin, Upper Burma. A description of the region, together with its history, appears in the Imperial Institute monograph on *Zinc Ores* (p. 33–34), but the following notes, by J. Coggin Brown [33], refer more particularly to the nature and structure of the principal ore-body (The Chinaman) : The main ore-channel at Bawdwin is 8,000 ft. long, and probably from 400 to 500 ft. wide, and is in a nearly vertical zone of combined faulting and shearing in rhyolite tuffs. The Chinaman ore-body is an enormous replacement deposit of argentiferous lead-zinc ore occurring on the hanging-wall side of the ore-channel. The axis of the thickest part of the sulphide ore strikes approximately 25° W. of N., and dips 70°–80° W. The hanging-wall is more or less regular, but the foot-wall is ill-defined, and there is a gradual passage from the solid mixed-sulphides of lead and zinc through a second-grade ore composed of dark grey tuffs infiltrated with silica, and containing nests and strings of sulphides, in which the metallic sulphides gradually become poorer, until unaltered rhyolite

tuff and, in some cases, true rhyolite are found. An ore carrying 24 per cent. of lead and 14 per cent. of zinc assayed 17 oz. of silver to the ton, and ore carrying 30 per cent. of lead and 26 per cent. of zinc assayed 40 oz. of silver per ton.

Almost the entire output of lead ore from India comes from the Bawdwin mines. From 1910 to 1916 inclusive the company (now the Burma Corporation, Ltd.) working the mines smelted a large quantity of slag left by the old Chinese workers, and during those years comparatively little ore was raised, but by 1915 the greater part of the slag had been worked off. In 1916 the output of lead ore from Bawdwin amounted to nearly 9,000 tons, and in the two following years to upwards of 50,000 tons per annum (see Table I, p. 35). The exports from India of lead for recent years is given in Table X.

Table X

Exports of Lead from India *

In long tons (2,240 lb.)

	1911–12.	1912–13.	1913–14.	1914–15.	1915–16.	1916–17.	1917–18.	1918–19.
To British countries :								
United Kingdom .	9,870	5,785	2,268	4,372	5,096	1,915	4,121	349
Ceylon . . .	—	1,307	1,110	2,036	4,031	4,536	6,093	5,807
Other British countries	161	30	43	—	554	1,100	133	850
Totals :								
British countries .	10,031	7,122	3,421	6,408	9,681	7,560	10,347	7,006
To foreign countries .	146	190	10	101	1,165	2,792	222	2,202
Grand totals .	10,177	7,312	3,431	6,509	10,846	10,352	10,569	9,208

* Annual Statement of Sea-borne Trade of India.

(Fiscal year ends on the 31st March in each year.)

AFRICA

Egypt

Important quantities of lead and zinc ores have recently been produced from the ancient mines at Gebel Rosâs, near the Red Sea, which were reopened in 1913 by the Compagnie Française des Mines de Laurium. The ores occur as replace-

ments in limestone, and consist of sulphides and carbonates. Analyses show up to 58 per cent. lead and 37 per cent. zinc.

NIGERIA

Lead and zinc ores occur in the Abakaliki district [34] [35]. A lode occurring at Alusi Hill, Ifotta, near Enyiba, which has been worked by the natives, carries galena, blende and siderite, and other deposits have been recognized in the vicinity. The following table, which is taken from the monograph on *Zinc Ores*, p. 35, gives the results of an examination undertaken at the Imperial Institute of six bulk samples from the Ifotta lode:

	Lead.	Zinc.	Copper.	Silver.
	Per cent.	Per cent.	Per cent.	Per ton.
1.	65·49	0·73	trace	2 oz 10 dwt. 15 gr.
2.	55·21	6·99	0·56	2 ,, 6 ,, 9 ,,
3.	38·87	3·49	trace	1 ,, 8 ,, 2 ,,
4.	33·31	1·11	0·088	1 ,, 19 ,, 20 ,,
5.	24·65	1·33	0·04	1 ,, 18 ,, 13 ,,
6.	0·82	30·40	0·12	7 ,, 12 ,,

RHODESIA

The deposit of Broken Hill, in North-Western Rhodesia, consists of irregular masses and impregnations in crystalline limestone. Galena and blende occur in intimate association, and there is an extensive development of oxidized ore. Owing to difficulties of treatment of the ore these deposits were for many years of little commerical value, but recently have received renewed attention with successful results.

SOUTH-WEST PROTECTORATE

Deposits in limestone carrying ores of lead, in association with those of copper and zinc, have been mined in the Otavi Mountains, and small quantities of ore exported to Germany. This colony has also sent considerable amounts of ore to the United States. During 1918 the Otavi Co. exported 7,358 long tons of ore containing 12 to 22 per cent. of lead.

Sudan

Lead ores are said to occur in Jebel Kutum, north of Kobe, in Darfur [36], but no commercial production has yet been recorded, although the deposit is stated to have been worked.

Union of South Africa

Deposits of lead ore are known in many places in the South African Union, but, on the whole, they have received but little attention, and their possibilities have not yet been fully proved. Throughout the dolomitic rocks of the Transvaal irregular deposits, pockets and impregnations of galena are found, but many of these are small and hardly of commercial importance, and in almost all cases decrease in value with depth. The most important occurrences hitherto mined are those of the Malmani district, where the ore is found in pipe-like deposits and impregnations in the Malmani Dolomites of the Transvaal System. The primary ores consist of galena and blende, while hemimorphite, calamine and copper carbonates are found in the oxidized zone. Small quantities of cinnabar are found. At Leeuwkloof, in the Pretoria district, the deposit consists of a large replacement of dolomite at its contact with the overlying shales of the Pretoria Series. About 700 tons of ore, averaging 73 to 75 per cent. of lead, and 2 to 4 oz. of silver to the ton, have been extracted from this deposit. A similar, but smaller, ore-body is mined at Rhenosterhoek, in the Marico district, where the ore carries 9 to 15 oz. of silver to the ton.

Veins carrying galena, sometimes associated with ores of gold, silver, copper and cobalt, are found in the Pretoria Series, and have been mined in the Pretoria, Marico and Rustenburg districts. In the Pretoria district the chief operating property is the Transvaal Silver Mine, where argentiferous galena, associated with iron and copper pyrites, copper carbonates and tetrahedrite, in a gangue of siderite, is found in a vein connected with a diabase dyke. At Edendale, a vein in the Pretoria Series, carrying galena and blende in a gangue of quartz and calcite, has been worked.

A vein of lead ore was formerly worked at Argent, fifty miles east of Johannesburg, and similar deposits are known in Northern Transvaal, Waterval Onder, Natal and Gordonia. At Potgietersrust the deposit occurs in altered (Pre-Cambrian) granite.

Other localities in the Transvaal where lead is or has been mined are Broederstroom, Dwarsfontein and Roodekrans, in the Pretoria district; Witkop, Bokkraal, Buffelshoek, Rietspruit, and Doornhoek, in the Marico district; and Windhuk, in the Pietersburg district. Many of the mines were closed down on account of the war.

In the Cape Province lead ores occur in several places, both as dolomitic replacements and as vein deposits. The best-known occurrence is that of the Maitland Mine, near Port Elizabeth, where galena occurs in a vein, in association with ores of copper, silver and antimony. Other occurrences are at Banghoek, forty miles west of Hopetown; in quartz veins at Knysna; at Richmond; and in the Beaufort West and Victoria West districts. In the Van Rhynsdorp district a large vein, carrying pyromorphite at the surface, has been located. Deposits are known to occur also in Bechuanaland and in Damaraland, and in the Bokkeveld Series of the Caledon and Swellendam districts, but many of these appear to be of little commercial importance.

In Natal galena has been found at Umsingi and in Umvoti County, but no extensive deposits are known. In the schists of the Mfongosi and Ngobevu Valleys, near the Tugela River in Zululand, a quartz vein carrying small quantities of galena has been prospected, but so far the results are not encouraging [37].

NORTH AMERICA

British West Indies

Lead ore is worked on a small scale in this region, as also in British Guiana, and insignificant quantities of lead are exported at irregular intervals, chiefly to Canada. At the present time these sources are quite unimportant.

Canada

Several important deposits of lead ore are worked in this country, and the annual production of lead is now about 20,000 tons, as will be seen from the annexed table, which has been compiled from the Annual Reports of the Department of Mines:

Production of Lead in Canada

In metric tons (2,204 lb.)

	1911.	1912.	1913.	1914.	1915.	1916.	1917.	1918.	1919.
British Columbia .	10,791	16,226	17,072	16,465	20,552	17,766	13,377	21,594	19,915
Yukon, etc. .	—	—	17	22	457	1,062	1,403	1,726	—
Totals . .	10,791	16,226	17,089	16,487	21,009	18,828	14,780	23,320	—

In 1917 the total production of lead concentrate was 58,801 tons. The chief deposits are situated in British Columbia, while less important ones occur in Quebec and Ontario. For full particulars regarding the Canadian lead ore occurrences reference may be made to the Annual Reports and other publications of the Department of Mines.

British Columbia.—By far the greatest production of lead ore in Canada comes from this province, chiefly from the Slocan district.

The veins of the Slocan district [38] occur in the clay slates and associated limestones and quartzites of the Slocan Series, believed to be of Pre-Cambrian age, and are connected with intrusions of granite. The ores comprise argentiferous galena, blende, and argentiferous tetrahedrite, with pyrite and chalcopyrite. Native silver occurs in the secondary zone. The common gangue is siderite or an allied carbonate, but quartz predominates where the veins intersect the igneous rocks. Blende and pyrite increase with depth, but many of the veins show a general impoverishment. Where the fissures intersect the bands of limestone there is frequently a good deal of metasomatic replacement and large shoots of ore occur. In these places the proportion of silver in the galena is much increased.

The chief producing property in 1917 was the Surprise Mine; others are the Standard, Lucky Jim, Galena M. & M. Co., and the Slocan Star. Much of the ore is smelted at Trail.

In the East Kootenay district there are important lead and zinc deposits from which a considerable production has recently taken place, notably from the Sullivan Mine. At the Monarch Mine a mill having a capacity of 80 tons a day is in operation, and the ore obtained is dressed to yield both lead and zinc concentrates. The former, which carries 67 per cent. lead, with under 9 per cent. zinc, and about 5 oz. of silver per ton, has been sent to Trail for smelting.

The Ainsworth district contains veins traversing schists, quartzites, and crystalline limestones of Pre-Cambrian age. In the latter rocks the deposits are irregular metasomatic replacements. The ores consist of galena, containing only a small quantity of silver, and blende, associated with pyrite, pyrrhotine and chalcopyrite. A typical sample of the ore is said to have yielded 20·8 per cent. zinc, 11·7 per cent. lead, and 2·5 oz. of silver per ton. Recently producing mines are the Whitewater of West Kootenay, and the Utica of Paddy Mountain.

Lead and zinc deposits occur also in the Nelson district, near Salmo, from which some production has taken place in recent years.

In the Yukon territory, near the borders of Alaska, deposits of galena, very rich in silver, have been opened up, and the production from this source has been rapidly increased within the last few years. The most productive undertaking has been the Silver King Mine, near Mayo. There is little doubt that many important deposits exist in this region, but the difficulties of transport at the present time militate against successful operations.

Ontario.—Although there are several occurrences of lead ore known in this province, but little work has been done upon them, and the output of ore has been irregular and intermittent. Many of the mines from which lead has been produced in the past are now abandoned. Accounts of the occurrences may be found in the Reports of the Ontario Bureau of Mines.

Some of the best known deposits are those of the Long Lake Mine, in Frontenac County; the Katharine Mine, in Hastings County; and the Victoria and Cascade Mines of Garden River, near Sault Ste. Marie.

In the Long Lake Mine, galena, intimately associated with blende, occurs as irregular replacements in crystalline limestone. Some of the ore-bodies are of large dimensions. The galena is argentiferous and the ore may contain up to 20 oz. of silver to the ton.

In the Katharine Mine, in Lake Township, Hastings County, operations have been conducted upon a vein carrying argentiferous galena and blende, associated with pyrite and pyrrhotine, in a gangue of calcite and siderite. The occurrence of ozokerite is noteworthy. The country rocks consist of schists and diorite.

Quebec.—The only productive lead mine at present in this province is the Notre-Dame-des-Anges, in Portneuf County. The deposit consists of small veins and impregnations in a micaceous quartzite, and there are two well-defined zones of ore. The ore consists of a more or less intimate mixture of galena and blende, associated with sulphides of iron and copper. Small quantities of gold and silver are present also. Some output was recorded from this mine during 1917.

Deposits containing galena and blende, intimately associated, have been mined on Calumet Island, Pontiac County, but difficulties connected with the treatment of the ore caused abandonment of the property, although a modern concentrating plant was installed. The ore occurs in irregular, pockety deposits in diorite associated with limestone and gneiss.

Nova Scotia.—No commercial production of lead ore is recorded from this province, although one or two deposits have been located. In Inverness County veins carrying galena, blende, pyrrhotine and mispickel occur in schists at Faribault Brook.

Recent Canadian exports and imports of lead are shown in Tables XI and XII.

Table XI

Imports of Lead into Canada *

(Bars, sheet, old, scrap and block; years ending 31st March)

In short tons (2,000 lb.)

Source.	1911.	1912.	1913.	1914.	1915.	1916.	1917.	1918.	1919.
United Kingdom	6,490	12,046	12,378	5,242	1,235	726	258	15	1
Other British countries	—	9	—	52	—	2	—	59	8
United States	115	1,471	736	1,018	7,467	25,064	6,271	6,532	5,493
Other foreign countries	7	20	—	4	—	—	—	—	—
Totals	6 612	13,546	13,114	6,316	8,702	25,792	6,529	6,606	5,502

Table XII

Exports of Lead from Canada *

In long tons (2,240 lb.)

To	1911.	1912.	1913.	1914.	1915.	1916.	1917.	1918.	1919.
United States	16	83	47	122	328	889	7,798	7,226·5	10,578
Other countries	1,412	—	89	—	1,126	47	—	0·5	735
Totals	1,428	83	136	122	1,454	936	7,798	7,227	11,313

* Annual Report of the Trade of Canada.

Newfoundland

At many places in this island lead ore has been found and, in some cases, worked, though, on the whole, with but poor success. The deposit at Buchan's River, Red Indian Lake, contains lead, zinc, silver and copper, with some gold, and has been exploited to a depth of several hundred feet.

AUSTRALASIA

Australia

Australia is by far the largest producer of lead ore in the British Empire, the output being derived almost entirely from the mines of Broken Hill.

New South Wales.—The famous deposit of Broken Hill [39] [80], discovered in 1883, was first worked for silver, then for silver and lead, and in recent years largely for zinc. At the present time it is one of the largest lead-zinc deposits in the world. The main ore-body, the outcrop of which formed the crest of the hill but has now been practically all removed, stretches for a distance of about one and a half miles in a north-east and south-west direction, with a maximum width of 100 ft. It was formerly classed as a large saddle reef, with downwardly tapering limbs, but the north-west portion is now regarded as the main ore-body, the south-east limb being a lobe or off-shoot from this. This portion of the deposit is impersistent and often thins out. There are other and smaller lodes in the vicinity. The country rock consists of highly metamorphosed sediments, folded into an anticline and penetrated by masses of granite and basic dykes.

The deposit has been followed to a depth of 3,000 ft., and still contains large bodies of ore. The gozzan, which extended downwards for about 300 ft., and varied in width from 20 to 100 ft., carried siliceous and manganiferous limonite, hæmatite and kaolin. Below this occurred large masses of cerussite and anglesite, with oxides and carbonates of copper, and abundant haloids of silver (*cerargyrite, embolite* and *iodyrite*). The proportion of silver in the ore was in places as much as 300 oz. to the ton. The ore of the primary sulphide zone, which was reached about 1893, consists of a

fine-grained mixture of galena and blende, associated with sulphides of iron, copper and arsenic, in a gangue of rhodonite, calcite, quartz and garnet. Wulfenite and fluorspar are rare occurrences.

Owing to the intimate association of the galena and blende their separation cannot be carried out by ordinary methods, and flotation is resorted to with highly successful results. The large quantities of tailing and residue, amounting to between five and six million tons, which accumulated in the earlier days when the zinc could not be successfully extracted, are now being similarly treated. They contain about 18 per cent. of zinc, with some lead and silver, and yield important productions.

Formerly the crude sulphide ore averaged about 25 per cent. each of lead and zinc, with 25 oz. of silver to the ton, but the grade is now lower and does not exceed 15 per cent. The dressed products consist of (1) lead concentrate, carrying about 65 per cent. lead, with 6 per cent. zinc, and (2) zinc concentrate, containing about 45 per cent. zinc, and 5 to 8 per cent. lead.

There are several companies mining the deposit, and the annual output of crude ore has been about 1,500,000 tons. Since 1917, however, production has been much retarded on account of local industrial troubles and general strikes.

Previous to the war about half the lead concentrate was smelted at Port Pirie, the remainder being sold chiefly to German firms and smelted in Belgium and Germany. At the present day the whole of the smelting is done in Australia, principally at Port Pirie.

Queensland.—The Burketown district, in the north-western corner of the State, contains several deposits of galena associated with blende, typical samples of the ores yielding on the average 13 per cent. galena and 10 per cent. blende. There are several groups of claims, such as the Silver King, Banner, Watson's, Tunnel Hill, Anglo-American, Britannia and Greater Britain. Many of the deposits are low-grade and of more importance as sources of zinc than of lead. The galena is commonly argentiferous.

The Mount Barker Mine, in the Eungella Goldfield, has

been worked for argentiferous galena, but the presence of a considerable amount of intimately associated blende has rendered the ore difficult of treatment.

South Australia.—The output of metallic lead from this State is due to the smelting of Broken Hill ore at Port Pirie. No important deposits of lead ore have as yet been located.

Victoria.—Although several occurrences of lead ore, associated with zinc, have been located in this State, so far no mining undertakings of any importance have been carried out upon them.

West Australia.—The chief lead occurrences in this State are situated in the Northampton district, extending over an area of about fifty miles in length. The veins, which are usually small but of considerable length, occur in garnetiferous granite in association with parallel basic dykes, and are often found along the junctions of the latter with the granite. The ore is mainly a high-grade galena and frequently occurs in shoots of from 500 to 1,000 ft. in length. Several of the veins yielded copper ore at the surface, but this gave place in depth to a mixture of copper and lead, and, finally, to lead ore only. In the Surprise Mine, at Geraldine, the ore assays 50 per cent. lead over a width of 10 ft.; the quantity of silver present is small, averaging only about half an ounce to the ton. The concentrates produced in this district average about 70 per cent. metal.

According to a recent Report of the State Mining Engineer, the Northampton field is capable of a greatly increased production, but requires more extensive development and organization, and the erection of suitable concentration plants as a necessary preliminary to successful operations on a large scale. At the present time there appear to be difficulties connected with the smelting of the concentrate produced. Before the war the ore was chiefly exported to England for smelting, this being considered the cheapest method of treatment, although the Fremantle Trading Company had local smelting works. Under present regulations the export of lead ore from Australia is prohibited, so that a local solution of the problem becomes necessary, and it has been proposed that a new central smelting establishment should be erected.

As, however, works already exist at Fremantle which are said to be capable of dealing with a greatly increased output, or, alternatively, the concentrate could be sent for treatment to the smelters in the eastern States, at Port Pirie and elsewhere, this proposal has met with opposition.

According to a recent estimate the value of the lead produced in West Australia up to the end of 1918 was £963,880 [40].

Tasmania.—There are several important lead-zinc deposits known in this island, but the output of ore has been irregular owing, it is said, to the intermittent working of the Zeehan smelters. The chief deposits are situated on the west side of the island in the Read-Rosebery district; others of importance are near Zeehan and at Waratah.

The Read-Rosebery ore-field has been proved over an area seven miles in length, extending from Mount Black on the north to Mount Read on the south. This region was formerly chiefly a copper producer. The country rock consists mainly of mica schist, with bands of limestone, slate, sandstone and quartzite, and intrusions of diorite. The ore bodies exhibit a banded structure, different bands being characterized by the predominance of a particular ore. The metallic constituents are blende, galena, pyrite and chalcopyrite. The galena is argentiferous, and some gold is present also. The gangue minerals, which are quite subordinate, comprise quartz, calcite, barytes, rhodochrosite, siderite and chlorite. The vertical extent of the ore so far observed is 2,700 ft.

In the Mount Read group of deposits [41] the chief undertakings are the Mount Read, Hercules, Ring P.A., and Jupiter Mines. The average compositions of the ores from the Hercules Mine, which has been so far the largest producer, are as follow:

	Zinc.	Lead.	Copper.	Silver.	Gold.
	Per cent.	Per cent.	Per cent.	Ounces per ton.	Ounces per ton.
Gossan	—	9·47	—	21·9	0·50
Lead ore	28·0	9·35	—	12·7	0·20
Zinc ore	40·8	7·0	—	9·7	0·157
Copper ore	—	—	4·4	2·0	—

It is estimated that the reserves of zinc-lead ore in this mine total over half a million tons.

Operations on these deposits were extended in 1900, from which date up to 1914 about 200,000 tons of zinc-lead ore and 2,500 tons of copper ore, having a total value of approximately £300,000, were produced.

The deposits of the Rosebery area [42] are worked by three companies, namely, the Tasmanian Copper Co., the North Tasmanian Copper Co., and the Primrose Mining Co. The ore of this district is said to have the following average composition: blende 43·3 per cent., pyrite 31 per cent., galena 10·4 per cent., chalcopyrite 1·2 per cent., tetrahedrite 0·1 per cent.; with 10 oz. of silver and 3 dwt. of gold to the ton. Operations are conducted at the Rosebery Mine, on the western slope of Mount Black, where several large and well-defined lodes have been opened up. Other properties are the Koonya and the Dalmeny Mines, in the former of which a considerable body of ore has been located.

The output of zinc-lead ore in this area during 1915 was 96,890 tons, in addition to which there were said to be over 200,000 tons of ore blocked out.

The Mount Lyell Co. have recently acquired the chief mines of the Read-Rosebery district and propose to treat the complex ore electrolytically.

Full particulars of the operations in this district will be found in the monograph on *Zinc Ores* in this series (pp. 19–23).

In the Zeehan district [43], where tin ore also occurs, lead-bearing veins and irregular deposits, from 60 to 200 ft. wide, occur in Lower Palæozoic rocks, in connection with granite. The region exhibits an interesting series of transitional types, ranging from tin veins in the granite to the copper-, lead- and zinc-bearing veins in the surrounding rocks, and the ores show considerable overlapping in their occurrence. Thus, in the lead-bearing veins the galena is sometimes associated with tin ore, and the occurrence of an argentiferous sulphide of tin is interesting. Compounds of antimony and sulphide of bismuth occur. The galena is highly argentiferous, the ore in certain cases containing as much as 200 oz. of silver to the ton. The upper parts of the veins carry oxidized lead

ores, together with native silver, silver chlorides, and silver sulphides.

Similar ore-bodies exist in the Dundas region, east of Zeehan, but so far these deposits have not been an important source of lead. Lead ore, in association with zinc ore, has been prospected and opened up in several places at McLean's Creek, on the west coast near Zeehan, and there are one or two mines at work, though hitherto the production has been small.

The mines of the Waratah district operate upon lodes carrying argentiferous galena associated with blende.

Australian Exports

Recent exports of pig lead, matte, silver ore and silver-lead concentrate are shown in Tables XIII, XIV and XV.

New Zealand

Although lead ores occur in several localities in New Zealand, so far little has been done to develop them commercially. In many cases lead is found as a subsidiary metal in gold and silver deposits.

The Hauraki Peninsula, in North Island, is extensively mineralized and contains an assemblage of veins connected with Tertiary volcanic rocks. Several of these deposits have been worked for gold with highly successful results, as in the Waihi and other mines, but there are many in which the proportion of base metals is high, and the district appears to contain large reserves of lead and zinc ores which merit attention.

Further particulars will be found in the Imperial Institute monograph on *Zinc Ores* (pp. 24–26).

Table XIII

Exports of Lead contained in Matte from Australia * †

In long tons (2,240 lb.)

To	1910.	1911.	1912.	1913.	1914–15.	1915–16.	1916–17.	1917–18.
United Kingdom	23,678	19,834	23,677	25,023	36,871	41,058	27,444	14,871
Other countries	—	33	1,436	1,202	—	—	—	712
Totals	23,678	19,867	25,113	26,225	36,871	41,058	27,444	15,583

† *No reported Exports* 1918–19.

Table XIV

Exports of Pig Lead from Australia *

In long tons (2,240 lb.)

	1911.	1912.	1913.	1914–15.	1915–16.	1916–17.	1917–18.	1918–19.
To British countries:								
United Kingdom	32,411	37,948	44,194	35,947	51,699	94,452	76,069	77,580
Other British countries	9,689	9,604	8,814	9,833	8,391	5,164	2,825	5,027
Totals (British countries)	42,100	47,552	53,008	45,780	60,090	99,616	78,894	82,607
To foreign countries:								
France	2,601	2,362	2,401	300	—	—	—	—
Germany	1,681	3,100	2,153	200	—	—	—	—
Russia	—	—	—	11,626	13,325	4,312	—	—
Japan	14,387	13,989	13,498	11,828	7,678	14,057	15,289	19,868
Other foreign countries	7,146	4,931	5,393	1,639	756	661	1,059	1,111
Totals (foreign countries)	25,815	24,382	23,445	25,593	21,759	19,030	16,348	20,979
Grand totals	67,915	71,934	76,453	71,373	81,849	118,646	95,242	103,586

(1910 to 1913 inclusive are calendar years; 1914 and later years are financial years ending June 30th.)

* *Annual Statement of Trade and Customs of Commonwealth.*

Table XV

Exports of Silver and Silver-Lead Ores and Concentrates from Australia *

In long tons (2,240 lb.)

	1909.	1910.	1911.	1912.	1913.	1914–15.	1915–16.	1916–17.†
To British countries:								
United Kingdom	2,831	4,832	1,044	2,207	5,331	4,468	171	1
To foreign countries:								
Belgium	7,845	6,661	5,703	8,090	563	256	—	—
Germany	5,578	10,607	5,796	5,965	5,818	506	—	—
Netherlands	5,283	20,001	8,960	44	225	—	—	—
Other foreign countries	2	—	—	—	25	—	—	—
Totals (foreign countries)	18,708	37,269	20,459	14,099	6,631	762	—	—
Grand totals	21,539	42,101	21,503	16,306	11,962	5,230	171	—
Total lead in ore (tons)	12,125	24,183	12,608	8,175	6,863	2,920	114	—
Lead in concentrate	49,771	55,370	93,652	67,700	111,927	15,820	5,444	1,851

The exports from N.S.W. in 1918 and 1919 were 3,178 and 2,425 tons respectively.
(1909 to 1913 inclusive are calendar years; 1914 and later years are financial years ending June 30th.)

* *Annual Statement of Trade and Customs of Commonwealth.*

† None in 1917–18. In 1918–19, 1 cwt. exported to United Kingdom.

CHAPTER III

SOURCES OF SUPPLY OF LEAD ORES (*continued*)

(*b*) FOREIGN COUNTRIES

EUROPE

Many large and important deposits carrying lead and zinc ores occur in Europe, and several have been worked for very long periods. With the deepening of the mines and the opening up of the lower zones, however, many of the deposits have become sources of zinc rather than of lead. Very many have been abandoned.

Austria

The largest deposits in this country are found in Carinthia. They occur in Triassic limestones and dolomites, and extend over an area nearly 100 miles long and several miles wide. The ores occur in flats, gash veins, and irregular deposits as fillings and replacements, and are closely connected with the faulting and jointing of the beds in which they are found. The mineralization is quite independent of igneous activity and has a close resemblance to that of Missouri, described later. The best known mining districts are those of Raibl and Bleiberg.

Although these deposits have yielded large quantities of lead ore, in the form of galena and cerussite, they are now noted more especially for their yield of zinc, and the ores produced are chiefly calamine and blende. Hemimorphite and hydrozincite occur in small quantities. The occurrence of large quantities of wulfenite has been a notable feature. Marcasite, pyrite and chalcopyrite accompany the ores, and

the common gangue minerals are calcite and barytes, though these are often practically absent.

The well-known deposits north of Graz, in Styria, consist of veins carrying galena, with 0·06 per cent. of silver, and blende, together with sulphides of copper and iron. The vein accompaniments are quartz, barytes, witherite and carbonates of iron and lime.

Some pre-war imports of dressed lead ore into Austria-Hungary are shown in Table XVI.

Table XVI

Imports of Dressed Lead Ore into Austria-Hungary *

In metric tons (2,204 lb.)

	1910.	1911.	1912.	1913.
From British countries :				
Australia	4,001†	—	1,980	6,054
From foreign countries :				
Germany	140	180	298	45
Russia	146	497	59	—
Serbia	1,394	15	—	—
Tunis	674	—	902	1,915
United States	—	508	1	41
Totals (foreign countries)	2,354	1,200	1,260	2,001
Grand totals	6,355	1,200	3,240	8,055

* *Statistik des Auswartigen Handels des Vertragszollgbeites der beiden staaten der Osterr-Ungar Monarchie.*

† Including 235 tons from United Kingdom.

Belgium

The well-known deposit of the Moresnet district [44] extends from Belgium into Luxembourg and Prussia, and is worked in the celebrated Vieille Montagne Mine, which has been responsible for a very large output of zinc ore.

The ore-bodies occur in Carboniferous limestone and present many similarities to those of Missouri. They show no association with any igneous rocks, but are clearly dependent upon a set of fractures trending north-west and south-east.

The ores occur as replacement deposits of the limestone, which has been extensively dolomitized, and are found chiefly along the contacts of shale beds, but also occupy fault fissures. Galena and blende, which are often intimately intergrown, occur only in depth, and so far no great quantities have been proved. The ores at present developed are chiefly carbonates, and enormous masses of calamine, occurring near the surface, have furnished a large production of zinc, though the output at the present time is small.

At Bleyberg, veins carrying lead and zinc ores occur in Carboniferous limestone and overlying coal measure shales, and have been extensively mined. Other occurrences of lead ore in Belgium are those near Liège and Verviers.

Belgium's production of lead for recent years is shown in Table II, p. 38, and also her imports of crude lead and her exports of manufactured lead are shown in Tables XVII and XVIII. The case of Belgium is peculiar inasmuch as although her domestic production is small she shows considerable exports, a fact due to her position as a halfway-house, with a large re-export trade. She was further the possessor of an important metallurgical industry, and it will be noticed in Table XVIII that a certain amount of lead was exported in the form of beaten, rolled or drawn metal.

Table XVII

Imports of Crude Lead into Belgium

In metric tons (2,204 lb.)

From	1910.	1911.	1912.	1913.
Australia	1,505	1,550	2,595	1,896
United Kingdom . .	1,423	2,526	1,464	2,441
Germany	1,344	2,244	1,564	3,238
Greece	8,649	5,499	680	12,054
Hamburg	2,533	1,464	2,414	190
Mexico	11,668	17,497	14,095	5,799
Spain	15,818	40,311	33,162	31,528
Turkey	7,422	3,930	5,126	6,081
United States . . .	1,908	3,672	2,636	2,543
Other countries . . .	1,598	4,809	4,303	6,422
Totals . . .	53,868	83,502	68,039	72,192

Table XVIII

Exports of Lead from Belgium

(Crude metal, and beaten, rolled or drawn)

In metric tons (2,204 lb.)

	1910.	1911.	1912.	1913.
United Kingdom	4,030	3,044	6,143	10,151
France	30,389	35,306	35,773	47,656
Germany	15,216	23,311	18,720	14,284
Netherlands	4,354	4,035	3,151	4,584
Russia	7,447	7,351	8,857	6,586
Other countries	4,370	4,915	5,879	3,970
Totals	65,806	77,962	78,523	87,231

Bulgaria

The Blagodat Mine, near Kustendil, has yielded ore containing 15 per cent. of lead and 25 per cent. of zinc. Deposits carrying lead and zinc are mined in several other places in Bulgaria, as at Sedmolchisleniza and Roupio, but the output of lead is small.

Czecho-Slovakia

There are several places in Bohemia where lead is or has been mined, the most important occurrences being those of Przibram, near Prague [45]. These mines have been worked for several hundred years and the deposits followed to depths of between 3,000 and 4,000 ft, but the output is now small. The veins, of which about forty have been worked, are contained within a narrow area, four or five miles in length, and occupy a series of folded and faulted Lower Palæozoic sediments, intruded by diorite and dykes of greenstone. A large fault, the Lettenkluft, traverses the district, bringing shales against grits, and where the lodes cross this junction they become impoverished in the shales. The richest ore occurs where the lodes cross the greenstone dykes.

The ores comprise galena and blende, with pyrite and chalcopyrite, and occasionally compounds of arsenic, antimony, uranium, cobalt and nickel. The galena is argen-

tiferous, containing up to ·5 per cent. of silver, and rich silver minerals, such as argentite, pyrargyrite, and native silver, were abundant in the oxidized zone. Calcite, siderite and quartz are the predominant gangue minerals, barytes being uncommon. The proportion of blende increased with depth.

Lodes carrying lead and zinc ores have been worked near Pilsen, and it is noticeable that in certain of the veins, in which the gangue is calcite and dolomite, the proportion of silver in the galena is higher than it is in others in which the gangue is barytes and fluorspar.

At Kuttenberg, east of Prague, and at Budweis, in Southern Bohemia, veins containing galena and blende, together with ores of silver, occur in gneiss.

The occurrences in North-western Bohemia are an extension of the deposits of the Saxon Erzegebirge, considered later. (p. 86).

France

Lead ores occur at many places in France, the chief deposits being situated in the metamorphic and associated igneous rocks of the Auvergne, in the Jurassic limestones and other rocks to the south and south-west of that region, in the Pyrenees, in the Alpine district of Provence, and in Brittany.

The deposits of the Auvergne district are found principally in the Departments of Puy-de-Dôme, Cantal, and Haute-Loire. The veins occur in gneiss and other metamorphic rocks, invaded by veins of fine-grained granite and quartz porphyry, and are contemporaneous with the older Tertiary volcanic rocks. The ores comprise argentiferous galena and blende, with pyrite, chalcopyrite, and compounds of antimony. Quartz is the chief gangue mineral, calcite and barytes being less frequent. The principal mines are situated at Pontgibaud.

In the Departments of Gard, Lozere and Lot, to the south of the Auvergne, the ores occur in limestones and dolomites of Jurassic age, and in granite and metamorphic rocks, as constituents of veins, some of which reach large dimensions, and as metasomatic replacements. The ores consist of galena and blende, with anglesite, pyromorphite, calamine, and hydrozincite as secondary products, while barytes is an im-

Table XIX—Imports of Argentiferous Lead into France *

In metric tons (2,204 lb.)

From	1910.	1911.	1912.	1913.	1914.	1915.	1916.	1917.	1918.
Greece	5,925	5,201	9,441	1,908	2,306	—	2,678	281	—
Spain	18,971	14,021	8,858	4,144	6,418	3,195	1,871	61	—
Other countries	138	420	11	6	42	758	4,646	3,935	7,452
Totals	25,034	19,642	18,310	6,058	8,766	3,953	9,195	4,277	7,452

During 1919 the total from "other countries" was 4,745 tons.

Table XX—Imports of non-Argentiferous Lead into France *

Blocks, bars, sheet, etc. In metric tons (2,204 lb.)

	1910.	1911.	1912.	1913.	1914.	1915.	1916.†	1917.†	1918.†	1919.
From British countries:										
United Kingdom	3,691	2,601	2,499	7,107	4,167	3,825	59	175	16	2,696
Australia	1,274	2,157	1,303	1,914	169	305	—	—	—	—
Totals (British countries)	4,965	4,758	3,802	9,021	4,336	4,130	59	175	16	2,696
From foreign countries:										
Belgium	28,682	32,556	32,234	47,675	24,520	1	—	—	—	67
Germany	1,058	1,990	1,302	3,669	1,663	—	—	—	—	—
Spain	1,673	1,268	1,712	5,975	1,465	32,844	53,130	44,391	37,877	46,071
Other foreign countries	2,637	8,755	6,917	4,473	215	9,056	1,355	12,552	6,703	6,242
Totals (foreign countries)	34,050	44,569	42,165	61,792	27,863	41,901	54,485	56,943	44,580	52,380
Grand totals	39,015	49,327	45,967	70,813	32,199	46,031	54,544	57,118	44,596	55,076

* *Tableau Général du Commerce et de la Navigation.*

† *Documents Statistiques . . . sur le Commerce de la France*, 1918.

portant constituent in some cases. The chief mining localities are Malines, Bleymard, Vialas and Planioles. Similar deposits are found near Angoulême, in Charente.

In the Pyrénées lead ores are found in the Departments of Ariège, Hautes Pyrénées, and Basses Pyrénées. At the well-known mines of Boulard de Sentein St. Lary, and at Girons, in Ariège, the deposits occur in Carboniferous limestone and yield argentiferous sulphides and carbonates of lead and zinc.

The deposits of Provence occur in the Department of Var, and consist of lodes traversing schists and quartzites. The vein contents, however, carry very little galena, and the chief ores are blende and its secondary products.

The best known occurrence in Brittany is that of Pontpéan, near Rennes, in the Department of Ille-et-Vilaine. The vein worked occurs in metamorphosed Silurian rocks and carries argentiferous galena and blende.

Some details of the import trade of France in lead and lead ore are given in Tables XIX, XX and XXI.

Table XXI

Imports of Dressed Lead Ore into France *

In metric tons (2,204 lb.)

	1912.	1913.	1914.	1915.	1916.	1917.
From British countries :						
Australia	6,043	—	2,914	—	505	—
From foreign countries :						
Algeria	15,886	17,813	5,928	9,541	21,173	18,615
Austria-Hungary	—	2,088	—	—	—	—
Belgium	880	1,213	411	—	—	—
Italy	11,677	13,951	11,807	—	9,871	3,915
Spain	1,562	1,908	543	282	1,363	824
Tunis	5,526	2,378	—	6,164	7,736	11,967
Other foreign countries	880	421	177	133	102	706
Totals (foreign countries)	36,411	39,772	18,866	16,120	40,245	35,027
Grand totals	42,454	39,772	21,780	16,120	40,750	35,027

According to *Documents Statistiques . . . sur le Commerce de la France*, 1918, the total imports for the years 1916, 1917, 1918 and 1919 were 40,750, 36,027, 20,335 and 11,968 tons respectively.

* *Tableau Général du Commerce et de la Navigation.*

Germany

This country has occupied a foremost place as a producer of lead ore, her annual output having been over 300,000 tons. This quantity, however, was insufficient to satisfy her large smelting industry, and her imports of ore were very considerable, the annual amount exceeding 100,000 tons. By far the most productive deposits have been those of Upper Silesia (to be subject to plebiscite), the output of ore from these mines being more than half the country's total production, while that of zinc ore was even greater (see p. 96).

Other deposits occur in Saxony, the Harz Mountains, Nassau, Westphalia, near Aix-la-Chapelle, and in the Black Forest, but many of them are now practically exhausted so far as lead is concerned.

The chief occurrences of lead ore in Saxony are in the neighbourhood of Freiberg. These well-known silver-lead deposits belong to a complicated system of fissure veins, varying in character and age, which are contained in biotite gneiss and other metamorphic rocks. They are most probably genetically connected with the post-Carboniferous granites of the Erzegebirge, and represent a higher portion of the same mineralization as that to which the celebrated tin-bearing veins belong.

The mining activity of this district extends over a period of between 700 and 800 years, but operations have now practically ceased. Depths of over 2,000 ft. have been attained in the workings.

The deposits have been the object of repeated study by many geologists and there is an extensive literature relating to them [46]. The veins have been classified into a number of types, which are grouped into an older and a younger series. To the former, which includes also the rich silver-quartz veins of the district (noble quartz formation) and the tin veins of the Erzegebirge, belong the pyritic lead veins and the rich silver-lead veins (noble lead formation) ; the latter comprises the barytes-lead veins. The pyritic lead veins carry argentiferous galena, blende and pyrite, with pyrrhotine, mispickel, and chalcopyrite, in a gangue of quartz ; while in the silver-lead veins the galena, which is highly argentiferous, is accom-

panied by sulpho-salts of silver in a gangue composed chiefly of ankerite and rhodochrosite. In the younger barytes-lead veins, which often are of considerable width, the galena is much poorer in silver and the gangue is composed of barytes, fluorspar, calcite and quartz; these veins sometimes carry cobalt and nickel minerals.

South of Freiberg, in the celebrated mining region of the Erzegebirge, which extends into Bohemia, some of the veins carry argentiferous galena and blende, as at Altenberg, Schneeberg, and other places, but the ores are usually dominated by the presence of chalcopyrite and mispickel, and are quite unimportant in comparison with those of tin, copper, silver and cobalt, for which this district is famous.

Many lead deposits, which have been extensively worked, occur in the region of the Harz Mountains, the most important being the numerous veins of the Clausthal Plateau, which have been mined since the thirteenth century [47] [48]. The veins, which have an average trend to the west-south-west, for the most part occupy faults in a folded complex of Devonian and Carboniferous sediments, and form a system of more or less parallel fissures linked together by numerous branches. They extend over an area fifteen miles in length and five miles in width. The main veins are composite and of considerable widths. They form ten parallel series of lodes which have been traced along the strike through practically the whole mineral area. The deposits have been mined to depths of 3,000 ft.

The chief ore is galena, but blende preponderates locally and increases with depth. Marcasite, pyrite, chalcopyrite and tetrahedrite occur also, and interesting rarities are the selenides of lead and copper. The gangue minerals comprise quartz, calcite, barytes and siderite, the latter two being limited to certain veins in the south.

The silver content of the galena is generally low, averaging from ·01 to ·05 per cent., but is sometimes as much as ·3 per cent.

On the northern slopes of the Harz Mountains, near Goslar, is the large deposit of Rammelsberg which has been worked for copper ores since the tenth century. This deposit, how-

ever, is of small importance as a source of lead though it has produced considerable quantities of zinc ore. The ore-bed, as it is called, is contained within a deformed series of Devonian slates, with which it is more or less conformable, and dips at a steep angle to the north. Its thickness varies considerably, but is usually about 10 ft., though in places it may swell to as much as 40 yards; its limits are generally sharply defined. The origin of this ore-body has been the subject of much controversy [49].

The ores, in their order of importance, are blende, chalcopyrite, galena, pyrite and mispickel, and they occur in intimate admixture. Barytes constitutes about the only gangue, but is seldom present in quantity. The zinc concentrate obtained carries 12 per cent. of lead, in addition to 25 per cent. of zinc.

Galena occurs in the lodes of St. Andreasberg, to the south of the Harz Mountains, noted for their rich silver ores, but the mining of these deposits, which reached a depth of nearly 3,000 ft., ceased in 1910.

In Nassau, two well-known deposits occurring in the Valley of the Lahn have been extensively mined. These are known respectively as the Ems and Holzappel veins, and consist of two zones of fissuring traversing Lower Devonian slates. The Ems series of veins, which extends from Braubach to Deerbach in an easterly and westerly direction, carries argentiferous galena, blende, chalcopyrite and pyrite in a gangue of siderite, calcite and quartz. Below the gossan there occurred a zone containing tetrahedrite and sulph-arsenides of nickel and cobalt. The complex ore is said to contain 4 per cent. lead, 2·5 per cent. zinc, and 2 oz. of silver per ton, and to yield (1) lead concentrate carrying 36 per cent. lead, and 11 oz. of silver per ton, and (2) zinc concentrate containing 44 per cent. zinc.

The Holzappel series of veins extends for a distance of nearly eight miles from St. Goar to Holzappel, and contains an assemblage of minerals similar to that of the Ems veins. A characteristic feature is the brecciated nature of the veinstones, in which the sulphides act as a cement.

The lead deposits of Westphalia comprise both veins in the Palæozoic slates and metasomatic replacements in limestone.

The former occur in the neighbourhoods of Coblenz, Arnsberg, Gladbach, Dusseldorf, etc , and present the usual types. Those of Coblenz have features in common with the Holzappel veins.

The metasomatic deposits are found in the *Stringocephalus* limestone of Middle Devonian age, the best-known occurrences being in the districts of Iserlohn and Brilon. The ore-bodies occur as irregular masses in the limestone, more especially at its junction with the underlying Lenne Slates. The ores comprise galena and blende, with their oxidation products, and there is a noteworthy amount of pyrite.

At Commern and Mechernich, near Aix-la-Chapelle, lead ore occurs as a dissemination in Triassic sandstone. The deposit, which is worked in open cuts, is of low grade, averaging 1·5 per cent. lead. The ore bed is about 65 ft. thick and occurs about 130 ft. below the surface. The ores are galena and cerussite, with a little chalcopyrite. Barytes occurs, generally filling small veins and fissures in the sandstone. The occurrence of the galena in small lumps or concretions dispersed through the sandstone has given rise to the name of *Knotenerz*, by which it is locally known. The mining of these deposits dates back for several hundred years, but is of little importance at the present day.

Similar deposits are found in other parts of Germany. In Bavaria and Würtemberg, gypsum-bearing beds belonging to the Upper Trias (Keuper) contain galena and chalcopyrite associated with blende and barytes. The Voltzia Sandstone, of Bunter age, has been worked in places in Rhenish Prussia and Lorraine for lead and copper ores, the minerals being cerussite, galena, chalcocite and copper carbonates.

The Kinzig Valley, in the Black Forest (Baden), contains an assemblage of veins of varied composition and age. They are contained principally in the older, gneissic, rocks, but also extend into the overlying Triassic and Permian sandstones. The veins have been classified into a number of types, grouped in two series, to the younger of which belong those carrying argentiferous galena. The district has yielded also ores of silver, cobalt and antimony.

At Munsterthal, in the same region, the lodes, which are in biotite-gneiss, carry galena and blende with subordinate

amounts of pyrite and ores of silver, antimony and arsenic. The gangue minerals are quartz, fluorspar, calcite, siderite and barytes. In the Schapbach region the deposits are similar.

At Wiesloch are metasomatic replacements in limestone, but these are of more importance as a source of zinc than of lead.

Germany, although a large producer of lead ore, also imported considerable quantities, a fact due to her big consumption. Her exports of lead, partly in a manufactured form, were round about 40,000 tons annually, a figure about half that of her imports of the metal, so that she was to a large extent dependent upon foreign supplies. A large portion of her imported lead ore came from Australia.

Details of some pre-war exports of crude and manufactured lead, and of imports of dressed ore and crude lead are given in Tables XXII–XXV.

Table XXII

Exports of Lead from Germany *

Rolled (sheet lead, etc.)

In metric tons (2,204 lb.)

	1910.	1911.	1912.	1913.
To British countries:				
United Kingdom . .	1,232	1,504	2,583	2,041
To foreign countries:				
Netherlands . . .	1,007	932	561	611
Roumania . . .	116	187	253	—
Russia	497	861	486	644
Sweden . . .	163	331	280	—
Switzerland . . .	405	405	354	416
Other foreign countries .	1,262	1,334	1,332	1,920
Totals (foreign countries)	3,450	4,050	3,266	3,591
Grand totals . .	4,682	5,554	5,849	5,632

* *Statistik des Deutschen Reichs Band* 260, *II.*

Table XXIII

Exports of Lead from Germany *

Crude (in blocks, pig, etc.)

In metric tons (2,204 lb.)

	1910.	1911.	1912.	1913.
To British countries :				
United Kingdom . .	823	1,260	1,110	1,298
To foreign countries :				
Austria-Hungary . .	12,026	13,063	18,150	14,661
Belgium . . .	990	2,387	2,231	6,497
France	1,916	246	483	3,352
Netherlands . . .	1,941	3,295	3,564	1,883
Russia	8,352	6,767	6,468	7,487
Switzerland . . .	3,154	2,877	3,207	3,116
Other foreign countries .	1,795	2,369	2,900	3,075
Totals (foreign countries)	30,174	31,004	37,003	40,071
Grand totals . .	30,997	32,264	38,122	41,369

* *Statistik des Deutschen Reichs Band 260, II.*

Table XXIV

Imports of Dressed Lead Ore into Germany *

In metric tons (2,204 lb.)

	1910.	1911.	1912.	1913.
From British countries :				
Australia . . .	93,481	124,819	98,252	127,021
British South Africa .	—	99	307	—
United Kingdom . .	73	807	811	271
Totals (British countries)	93,554	125,725	99,370	127,292
From foreign countries :				
Austria-Hungary . .	6,771	6,163	9,337	2,045
Belgium . . .	1,659	1,500	970	497
China	263	1,321	3,596	1,279
France	3,100	3,008	435	—
South-West Protectorate .	—	44	1,466	913
Peru	1,274	1,748	2,563	2,118
Russia	1,489	2,412	2,039	2,702
Spain	1,120	467	422	—
Other foreign countries .	2,921	1,210	2,029	6,151
Totals (foreign countries)	18,597	17,873	23,477	15,795
Grand totals . .	112,151	143,598	122,847	142,997

* *Statistik des Deutschen Reichs Band 260, II.*

Table XXV

Imports of Lead into Germany *

Crude (in blocks, pig, etc.)

In metric tons (2,204 lb.)

	1910.	1911.	1912.	1913.
From British countries :				
Australia . . .	8,791	6,697	4,103	2,839
United Kingdom . .	4,184	6,135	3,721	3,923
Totals (British countries)	12,975	12,832	7,824	6,762
From foreign countries :				
Belgium . . .	29,063	33,798	33,165	13,973
Italy	5	3	757	873
Mexico	2,320	3,314	1,104	20
Netherlands . . .	514	746	1,266	835
Spain	13,917	11,788	24,370	42,793
Sweden	535	517	1,022	680
United States . .	20,331	35,843	22,928	16,273
Other foreign countries .	1,882	1,699	1,149	1,554
Totals (foreign countries)	68,566	87,708	85,761	77,019
Grand totals . .	81,541	100,540	93,585	83,781

* *Statistik des Deutschen Reichs Band* 260, *II.*

Greece

There are many localities in this country where lead and zinc ores occur as metasomatic replacements in limestone, the largest and best-known deposits being those of Laurium, south-east of Athens, which have been mined from early times.

According to Hofman [4/p.1] the silver-lead mines of Laurium "were in operation before 560 B.C.; they flourished 100 years later, and were considered to be worked out at the beginning of our era. In 1863 they were reopened by a French company which erected smelting works and treated new ores, and the ancient concentration- and slag-dumps; the works are in operation at present."

The ores are contained in low-dipping beds of limestone, separated from one another by interstratifications of shale, and the ore-bodies occur chiefly along the contacts, forming a series of parallel layers, varying in thickness from 2 to 40

ft. and traceable for distances of upwards of a mile. There are three main horizons.

The primary ores consist of argentiferous galena and blende, in a gangue of siderite, while in the upper parts of the deposits occur cerussite, calamine, hæmatite and gypsum. Of great interest are the oxychlorides of lead which have been formed by the action of the sea water on the ancient slag heaps.

Argentiferous lead ores have long been worked in the islands of Milos, Pharos and Santorin, in the Ægean Sea. The deposits are associated with volcanic rocks, and carry, in addition to galena, blende, chalcopyrite and pyrite, with frequently barytes as a gangue.

Hungary

In the region of the Carpathian Mountains occurs an extensive series of Tertiary volcanic rocks with which are associated an interesting assemblage of mineral veins. These veins are notable for the great variety of minerals occurring in them, including gold tellurides, rich silver ores, galena, blende, pyrite, marcasite, chalcopyrite, tetrahedrite, bournonite, jamesonite, stibnite and cinnabar, while the gangue minerals comprise calcite and other carbonates, barytes, zeolites, and fluorspar. The various minerals, however, are subject to local distribution.

The most important ores are those of gold and silver, but in certain veins galena preponderates.

The chief mining districts are those of Schemnitz-Kremnitz, Nagybanya-Felsobanya-Kapnik and the Transylvanian Erzegebirge. Mining operations are extremely old and date from the eleventh century or before. The industry was flourishing about the sixteenth century. A large number of the mines are state-owned.

In the Schemnitz-Kremnitz district the Johann and Spitaler lodes are chiefly galena-bearing, and have been mined for that ore. Secondary minerals, such as cerussite and pyromorphite, were present in large amount.

The chief lead occurrences of the Nagybanya-Felsobanya-

Kapnik district are at the last-named places, more especially Kapnik. The galena, which is often accompanied by blende, is richly argentiferous.

The district of the Transylvanian Erzegebirge is noted especially for its gold tellurides, and ores of lead are quite subordinate. The mines of this area are drained by the celebrated Franz-Joseph adit, which has a length of 5,012 metres.

Italy

The chief deposits are situated in Sardinia. Others are found in Tuscany, Lombardy and Piedmont.

In the neighbourhood of Iglesais, in Southern Sardinia, there are numerous occurrences of lead ore, both in lodes traversing granite and metamorphic Cambrian and Silurian strata, and as large replacements in dolomitic limestones of Orodovician age. The deposits are mined principally at Montevecchio, Monteponi, Malfatano, and other places.

At Montevecchio the veins, which vary in width from mere stringers up to lodes 50 to 100 ft. wide, carry argentiferous galena, with 0·08 to 0·17 per cent. of silver, and blende, with sulphides of copper and iron. The secondary ores comprise cerussite, pyromorphite, crocoisite, and carbonate of iron, together with native silver, ruby silver, and horn silver. Cinnabar and compounds of arsenic, antimony, nickel and cobalt occur also. The gangue minerals are principally quartz and calcite, but barytes, fluorspar and zeolites are found. Where the veins are associated with limestone there is an extensive metasomatic replacement of the country rock, and a predominance of zinc in the form of calamine and blende.

At Monteponi [50] the deposits consist of large irregular replacements in limestone, occurring chiefly along normal or faulted contacts with slates. The primary ores are galena and blende, the former occurring more particularly in the upper zones. Near the surface there are large deposits of the secondary zinc ores, calamine and hemimorphite. Similar ore-bodies occur at Malfatano, and the district is now of more importance as a source of zinc than of lead, being, in fact, one of the most productive zinc regions in Europe.

It is known that the "Romans worked lead mines in Sardinia which had been opened up by the Phoenicians and operated by the Carthaginians" [4/p. 2].

In the Campiglia Marittima district of Tuscany the lodes occur in Palæozoic slates and carry argentiferous galena, containing from 0·3 to 0·5 per cent. of silver, blende, chalcopyrite, and antimonial lead ores, together with small quantities of cassiterite and compounds of cobalt and bismuth, in a gangue of quartz, calcite and siderite. The deposits are mined at Bottino.

Near Trent, and at other places in the Tyrol, occur many well-known lead and zinc veins, in which the galena is often highly argentiferous. At Pfundererberg the galena carries from 0·3 to 0·6 per cent. of silver, and the associated sulphides of copper and iron are auriferous.

Recent imports of crude lead into Italy are given in Table XXVI.

Table XXVI

Imports of Pig Lead into Italy *

In metric tons (2,204 lb.)

	1912.	1913.	1914.	1915.	1916.	1917.	1918.	1919.
Australia . .	—	—	—	—	—	—	—	—
United Kingdom	717	283	870	180	152	377	74	119
France . .	1,816	126	155	1	406	226	—	—
Spain . .	12,661	10,316	7,413	12,227	11,960	21,081	6,567	6,132
United States .	—	26	155	4,340	763	4,510	260	211
Other countries	433	743	1,221	500	1,077	76	5,540	5,759
Totals .	15,627	11,404	9,820	17,326	14,358	26,270	12,456	12,221

* *Ministero del Finanze. Statistica del Commercio Speciale.*

Norway

Lead ores occur near Vefsen and at other places in Norway, but so far the deposits have not been extensively exploited. The lodes occur in gneisses, schists, and Palæozoic rocks in association with gabbro and granite, and carry argentiferous galena, with from 0·2 to 0·8 per cent. of silver, and blende, together with silver ores and sulphides of iron, copper and antimony.

Poland

The deposits of Poland, which were formerly more extensively mined than at present, are an extension of those in Upper Silesia, considered below. They have been mined chiefly at Boleslaw, Szakowa, Trzebinia and Olkusz, but the occurrences are less important than those of Germany.

Portugal

This country is not an important producer of lead ore though several deposits are known. In Oporto, lodes containing argentiferous galena form part of a series of veins in which cassiterite, wolfram, and ores of antimony occur, but the deposits are not at present a source of lead.

Russia

Lead ores have been mined in the Caucasus and in Siberia, but detailed accounts of the deposits are not easily obtained. A large deposit carrying galena and blende is being worked at the Ridder Mine in the Semipalatinsk district of South-western Siberia. The ore-body is estimated to contain nearly a million tons of high-grade sulphide ore, and about 2,500,000 tons of low-grade ore.

Spain

This country, formerly the largest producer of ore in Europe, ranked only second to the United States in the world's production. The chief deposits are near Linares, in the Sierra Morena, and at Ciudad Real, to the north of that region. Others are those in the Province of Murcia, in the south-east; north of Almeria, in Granada; and in the Guadalajara district, north-east of Madrid. The metasomatic deposits of Santander, in the north, are essentially sources of zinc.

At Linares the lodes traverse granite and Silurian slates and quartzites. The ore is almost exclusively galena, only slightly argentiferous, and blende and pyrite are practically absent. The principal veinstone is quartz, with small amounts of dolomite and occasionally barytes and siderite. Cerussite

occurs in the oxidized zone. *Linarite,* the basic sulphate of lead and copper, is found here.

At Ciudad Real the deposits are similar, but the galena is more argentiferous, containing from 0·4 to 0·5 per cent. of silver.

In the Province of Murcia, around Cartagena and other places, there are lodes traversing slates, and metasomatic replacement deposits in limestone. The galena is associated with blende and pyrite and is richly argentiferous. Ores of silver occur, and the gangue minerals are calcite and siderite.

The lodes in the district north of Almeria, in Southern Spain, carry argentiferous galena associated with ores of copper in a gangue of barytes, strontianite and siderite. Secondary silver ores occur in the upper parts of the veins and have been extensively mined.

Similar deposits occur at Guadalajara in Central Spain, where the lodes are in gneiss and schist. The veins carry considerable quantities of barytes.

Tables XXVII and XXVIII give recent Spanish exports of crude and argentiferous lead.

Sweden

The largest deposit of lead ore worked in Sweden is that of Sala, to the north of Stockholm, where the ores occur as metasomatic replacements in a metamorphosed dolomitic limestone occurring as lenticles in crystalline schists. The main ore is galena, with a high percentage of silver, while blende and pyrite are subordinate.

The well-known deposit near Ammeberg is principally characterized by the presence of blende, though a small proportion of galena is present. The zinc concentrate produced carries 3 per cent. of lead.

Upper Silesia

The well-known and important deposits of Upper Silesia [51] [52] occur in the south-eastern corner of the province, on the borders of Russia and Austria, and extend across the

	1910.	1911.	1912.	1913.	1914.	1915.	1916.	1917.
To United Kingdom . .	61,765	56,932	52,969	47,628	66,312	—	—	—
,, Belgium	11,266	31,736	32,796	30,635	10,460	—	—	—
,, France	4,838	11,395	6,227	5,106	10,939	53,673	72,742	46,649
,, Russia	11,933	16,419	11,177	5,532	13,623	—	—	—
,, Other countries . . .	46,405	55,411	41,629	38,308	29,979	93,252	79,678	86,911
Totals	136,207	171,893	144,798	127,209	131,313	146,925	152,420	133,560

Table XXVIII

Exports of Argentiferous Lead from Spain *

In metric tons (2,204 lb.)

	1910.	1911.	1912.	1913.	1914.	1915.	1916.	1917.
To United Kingdom . .	25,240	21,817	23,821	21,529	19,516	12,143	21,505	20,954
,, France	24,548	3,875	14,624	16,386	1,942	—	2	465
,, Other countries . . .	5,392	5,855	2,046	9,604	—	—	—	—
Totals	55,180	31,547	41,491	47,321	21,458	12,143	21,507	21,419

* Spanish Trade Returns.

frontiers into Galicia and Russian Poland. It is said that mining in this district dates back to the sixteenth century. The principal deposits occur in the neighbourhoods of Tarnowitz, Miechowitz, Beuthen, Scharley and Dombrowka.

The ores occur in a mass of dolomite, about 250 ft. thick, belonging to the Muschelkalk division of the Trias, the particular ore-bearing horizon being in the upper portion of the Lower Muschelkalk, known locally as the Upper Wellenkalk or Schaumkalk. These beds form part of a series of Triassic and Permian rocks occurring in flat synclines and resting unconformably upon Carboniferous rocks which outcrop around them. There are coalfields in the vicinity.

The ore-bodies are replacements of the dolomite, and occur at two horizons about 40 to 60 ft. apart. The lower zone often rests upon a bed of pyritic clay. The two zones are connected by ore-bearing fissures, but the upper one is subject to great irregularity both in position and extent, and is often absent. The richest sections of the deposits are associated with fault fissures.

The ores consist of galena, blende, calamine, hemimorphite and cerussite, with abundant marcasite, the latter containing a little arsenic and traces of nickel.

The distribution of the ores is subject to much variation, and while in some places the deposits may consist almost entirely of lead ore, in others they are composed predominantly of zinc ore, while mixtures of both are common. On the whole, however, it may be taken as a general rule that galena and oxidized zinc ore preponderate in the upper zone, while blende and marcasite are dominant in the lower. Galena occurs more particularly in the neighbourhoods of Tarnowitz and Tröckenberg. It forms sheet-like bodies, varying from a few inches to a foot or more in thickness, and occurs also in irregular masses and nests.

The ores produced from this district are now said to contain, on the average, 17 per cent. of zinc and 5 per cent. of lead. The galena contains a little silver (·02 to ·03 per cent.), and traces of copper, antimony and gold have also been detected in analyses of furnace products.

There has been much discussion concerning the genesis of

these ores, but they are now generally attributed to the action of ascending hydrothermal solutions, which were responsible not only for the deposition of the ores but also for the dolomitization of the limestone. The district is much faulted, the fissures passing down into the underlying Carboniferous rocks, so that suitable channels for the ascent of the ore-bearing solutions were available. The formation of the oxidized ores from the original sulphides was a subsequent process connected with the circulation of waters of atmospheric origin. At the outcrop of the dolomite occur considerable irregular masses of ferruginous secondary zinc ores, calamine and hemimorphite, which are of great economic importance and have rendered this district famous as a zinc producer.

Yugo-Slavia

Serbia.—Lead is being mined at Cerveni Brey and Kosmaj in Belgrade, and also in the Departments of Podrinji and Rudnik [53].

Babe is a large lead mine, five miles from the Ralja railway station, with which it is connected by a narrow-gauge railway. In 1916 the Austrians were working the mine, and were extracting from it daily one car of picked, and 100 cars of ordinary ore, which were sent inland to be smelted [54].

Bosnia.—The lead ores of Bosnia occur in veins associated with andesitic lavas, slates and quartzites. The ores consist of argentiferous galena, with 0·2 per cent. of silver, and blende, with pyrite and compounds of copper and antimony.

Carniola.—At Laibach, in Carniola, ores of lead and zinc, accompanied by cinnabar and barytes, occur in fissure breccias in Carboniferous sandstones and shales.

ASIA

Asia Minor

The principal silver-lead mines in Anatolia are those of Balia-Karaidin in Brusa, and Bulgar-Maden in Konia. In 1913 the output from the former mines amounted to 13,076 tons of lead [55]. The lodes are numerous and vary in thick-

ness from 1 ft. up to 35 ft. The ore averages 12 per cent. lead and 6½ per cent. zinc [56]. The argentiferous galena occurs in fissures in augite-andesite near its contact with limestone (Carboniferous), the fissures being parallel to the contact zone. Ore occurs in the limestone at points where it underlies andesite [57]. The mines were shut down during the war. The Bulgar-Maden mines have been worked by the peasants for nearly eighty-five years. "The deposits are the result of contact action of micro-granulites, which have been intruded into the Palæozoic limestones." The annual yield amounts to about 400 tons of lead [55]. Narrow, rich veins of argentiferous and auriferous galena occur around Karahissa (Sivas). The ore is associated with antimony, while near Smyrna lead ores are associated with zinc [57]. At Bulgar-Dagh (Konia) argentiferous ore is raised, averaging 75 per cent. lead. In the vilayet of Aidin, silver-lead mines occur near Sokia, which from 1911 to 1913 yielded an average of 14,000 tons of lead. In Angora, silver-bearing lead ore is found in various mines which are State-controlled. At Karalar, Kastamuni, a silver-lead mine was worked for some years before the war [57]. Important silver-lead deposits occur at Keban Maden (Mamuret), on the Euphrates.

China

The largest and foremost lead mine in China is that of Shui-ko-shan in Hunan Province, Central China, an interesting description of which has recently appeared in the *Mining Magazine* [58]. According to this account the mine has been worked spasmodically for the past 300 years on primitive Chinese lines. It was reorganized by a European company about 1902, and a plant designed to handle 100 tons of ore daily has been erected. During 1914, 55,087 tons of ore were treated, giving 14,420 tons of zinc concentrate and 4,977 tons of lead concentrate. A large proportion of the ore, more than half in fact, is hand-picked, and the old Chinese floors are still utilized for the treatment of the fines.

From 1896 to 1912, inclusive, the mine produced a total of

100,683 tons of zinc concentrate and 41,837 tons of lead concentrate.

The occurrence consists of large irregular ore-bodies of blende and galena, with pyrite and chalcopyrite in limestone (Carboniferous ?) at and near the contact with syenite, but the ore-deposit itself appears to be of metasomatic origin.

The crude ore is said to contain from 19 to 33 per cent. of lead, from 23 to 29 per cent. of zinc, and about 20 oz. of silver to the ton. The lead concentrate produced carries 73 per cent. lead, about 8 per cent. zinc, and 30 oz. of silver per ton, while the zinc concentrate carries 30·5 per cent. zinc, 10·4 per cent. lead, and 5 oz. of silver per ton.

According to the *Mineral Industry* for 1917 there are ten mines successfully operated by Chinese companies in the province of Hunan. These are Kianghua, Pinghsien, Liangsiang, Kueiyang, Liling, Lingwu, Liuyang, Hengyang, Suikouling and Chowkiagang.

In the province of Chi-li veins carrying lead and zinc ores, in association with rich silver minerals and compounds of arsenic, have been mined.

Indo-China

Lead ores are found in Annam and Tonkin, but usually in deposits noted more especially for their zinc content.

At the Bong-Mieu mines, about 100 km. south-west of Tourane, galena and pyritic concentrates are obtained from the arsenopyrite lodes during the extraction of gold. The Quan-Son deposit, in the province of Thanh-Hoa, consists of blende and galena in Triassic limestone near the contact with schists. Work on a fairly large scale has been done, and some hundreds of tons of ore have been extracted. Argentiferous lead and blende were at one time worked by the Chinese at Moa-Ha, in the province of Vinh, but the deposits are now abandoned owing to difficulties with water.

In Tonkin, the Trang-Da mine on the left bank of the River Claire, formerly worked by the Chinese for galena, has been operated since 1906 by the Société Civile de la Mine de Trang-Da. This company has mined about 90,000 tons of

calamine, but at the present time the mine is producing galena mixed with various percentages of pyrite and blende. The country rocks consist of limestones and schists.

At the Lang-Hit mines, 17 km. north of Thai-Nguyon, galena in small quantities occurs with blende and calamine. The ore occurs in parallel fractures in similar country to that at Trang-Da, and maximum deposition is found where these fractures are intersected by secondary ones.

Galena, associated with brown hæmatite, calamine and cerussite in a baritic and flinty gangue, occurs at Pia-Ka in much fractured limestones and schists.

JAPAN

This country has a number of lead-ore deposits, the most important being that which is worked at Kamioka, in the province of Hida. The ore-body is a contact deposit occurring at the margin of a quartz porphyry intrusive into gneiss, and carries both galena and blende. The lead concentrate produced is smelted locally.

At Akita, in the island of Sado, on the west coast, occur a series of veins connected with Tertiary volcanic rocks. In certain of these argentiferous galena, associated with sulphides of silver, zinc and iron, occurs and is mined. Ores of copper and manganese also are produced in this region. Lead ore is mined in similar deposits near Tokyo.

Some recent imports of lead into Japan are given in Table XXIX.

Table XXIX

Imports of Lead into Japan

In long tons (2,240 lb.)

	1910.	1911.	1912.	1913.	1914.	1915.	1916.	1917.	1918.*
Ingots and slabs	11,528	14,435	7,867	14,643	15,257	14,300	20,480	15,519	29,783
Plates and sheet	356	261	410	152	178	45	—	—	—
Tea lead . .	809	835	760	544	453	1,103	899	536	271
Totals .	12,693	15,531	19,037	15,339	15,888	15,448	21,379	16,055	30,054

* Ten months.

AFRICA

The bulk of the lead ore at present produced in Africa comes from the countries bordering the Mediterranean. The ore is largely exported as such, only small quantities being smelted locally.

Algeria

Lead ores are mined here in a number of localities, and important quantities have been exported to France. Many of the deposits are metasomatic replacements of the Tertiary Nummulitic Limestone, which is well developed in the region of the Atlas Mountains. The ores of lead are associated with those of zinc, the latter often being predominant. One of the principal producing mines, so far as lead is concerned, is that of Oued Moziz, in the Department of Oran.

Tunis

The deposits of this country, like those of Algeria, are principally metasomatic replacements in Nummulitic Limestone, along the contacts of schists and quartzites. The galena is seldom argentiferous and is generally associated with considerable quantities of blende. Cerussite and calamine are of frequent occurrence.

Before the war several thousand tons of lead ore were being annually exported from Tunis to France, the United Kingdom and Austria-Hungary. France also received small quantities of lead.

NORTH AMERICA

The output of lead ore in America is very considerable, since the United States and Mexico together produce nearly half the world's total annual output.

Mexico

Large quantities of lead ore are mined in this country, and for many years it has maintained a foremost place among the world's producers. Many of the rich silver mines for which this region is noted have become, with the deepening of the workings, important sources of lead. This metal is very

generally distributed in the numerous veins which occur in association with Tertiary volcanic rocks throughout the mountainous region of the Sierra Madre. Generally speaking, these veins carry rich silver ores in the upper zones, and galena and blende, in association with sulphides of copper and iron, in the deeper zones.

Deposits of lead ore occurring as metasomatic replacements in limestone are found in several parts of Mexico. One of the most celebrated is that of Sierra Mojada, where large ore-bodies occur at or near the contact of the limestone with a breccia. The galena is exceptionally rich in silver. In the State of San Luis Potosi the ores consist principally of cerussite and pyromorphite, in association with native silver and silver chloride.

Jamesonite is mined near Zimapan [59].

The disturbed conditions during the Mexican revolutions caused a general stoppage of mining, and the output of lead ore, among others, seriously declined. During the last few years, however, operations have been largely resumed, and in 1917 considerable amounts of high-grade lead ore were produced from the mines of Santa Barbara, Cuatro Cienegas and Santa Eulalia, while the Angangueo Mines in Michoacán were reopened.

Recent Mexican productions of lead in metric tons were: for 1916, 19,970; for 1917, 64,125; for 1918, 98,837; and for 1919 (9 months), 50,534.

United States

This country is the world's largest producer of lead ore, and contains some of the most remarkable deposits known. A valuable account of the occurrences together with a history of the mining and treatment of the ores was given by Ingalls in 1908 [60], whose work has furnished much of the information given here.

Following Ingalls we may conveniently group the lead-producing districts of the United States into three regions as follow: the Atlantic Coast, the Mississippi Valley, and the Rocky Mountains and Pacific Coast. The chief production now comes from the Mississippi Valley.

Table XXX, taken from *Mineral Resources of the United States for* 1917 [61/p. 888] shows the output of lead-producing ores from the several States during that year, and their recoverable lead content.

It will be seen that the recoverable lead content of all the ore was 628,321 short tons. To this has to be added 22,628 short tons of lead obtained as a by-product from other kinds of ore. The percentages of total lead derivable from the several kinds of ore were:

Lead ores	69·1
Lead-zinc ores	26·8
Zinc ores	0·6
All other ores	3·5
	100·0

The Atlantic Coast

The mines of this region were never very large producers, though they played a not inconsiderable part in the early history of lead mining in the United States, but at the present time they are mostly abandoned and of little importance. The chief are those near Rossie, St. Lawrence Co., N.Y.; at Guymard, Ellenville, and Wurtsboro, near Port Jervis, N.Y.; and in Wythe Co., Virginia. The latter are of more importance as a source of zinc than of lead. Deposits of lead ore are found also in New England, North Carolina and Tennessee.

The Mississippi Valley

This area is characterized by a widespread occurrence of lead and zinc ores, these being found in the States of Missouri, Arkansas, Oklahoma, Kansas, Illinois, Iowa and Wisconsin, though they are not everywhere of sufficient importance to warrant exploitation. The largest deposits occur in Missouri. The chief mining undertakings are located in three districts which may be referred to as:

(1) *South-eastern Missouri.*

(2) *South-western Missouri, including neighbouring portions of Kansas and Oklahoma (Joplin district).*

(3) *Wisconsin-Iowa-Illinois district (Upper Mississippi Valley).*

Table XXX

Production of Lead in the United States in 1917

(By States and kinds of ore, in short tons)

State.	Lead ores.			Lead-zinc ores.			Zinc ores.		
	Crude ore.	Recoverable lead content.	Percentage.	Crude ore.	Recoverable lead content.	Percentage.	Crude ore.	Recoverable lead content.	Percentage.
Alaska	42	8	19·0	—	—	—	—	—	—
Arizona	82,285	8,145	9·9	49,071	3,081	6·3	62,839	91	0·1
Arkansas	—	—	—	—	—	—	203,600	382	0·2
California	29,651	2,694	9·1	26,501	3,803	14·4	125	—	—
Colorado	103,081	10,344	10·0	412,371	13,372	3·2	140,455	500	0·4
Idaho	1,448,285	137,510	9·5	1,118,075	58,938	5·3	19,269	301	1·6
Illinois	—	—	—	327,340	594	0·2	—	—	—
Iowa	—	—	—	1,000 *e*	34	3·4	—	—	—
Kansas	—	—	—	903,400	3,025	0·3	—	—	—
Kentucky	—	—	—	—	—	—	9,000 *e*	—	—
Missouri	5,887,900	204,545	3·5	11,136,100	29,611	0·3	—	—	—
Montana	28,923	2,778	10·0	726,280	5,728	0·8	258,846	1,770	0·7
Nevada	66,614	7,678	11·5	27,943	2,400	8·6	18,393	22	0·1
New Hampshire	—	—	—	3,000	48	1·6	—	—	—
New Mexico	17,426	2,818	16·2	10,899	542	5·0	135,129	697	0·5
North Carolina	32	1	3·1	—	—	—	—	—	—
Oklahoma	—	—	—	3,523,200	26,358	0·8	—	—	—
South Dakota	369	34	9·2	—	—	—	—	—	—
Tennessee	—	—	—	61,638	2,525	4·1	883,341	6	0·0006
Texas	—	—	—	—	—	—	—	—	—
Utah	638,071	68,623	10·8	421,704	19,394	4·6	6,535	30	0·5
Virginia	—	—	—	34,211	855	2·5	990	4	0·4
Washington	16,407	4,870	29·7	14,953	23	0·2	114	—	—
Wisconsin	—	—	—	3,014,800	4,139	0·1	—	—	—
Totals	8,319,086	450,048	5·4	21,812,486	174,470	0·8	1,738,636	3,803	0·2

e = estimated.

The first two constitute the *Ozark* region of some authors [62] [63]. In 1917 this area produced 381,815 short tons of concentrate.

The deposits are contained in gently-dipping Palæozoic limestones, ranging in age from Cambrian to Lower Carboniferous (*Mississippian*), and are found usually within a few hundred feet of the surface. The ores occur in dolomitic and cherty limestones, as disseminations ; in more or less horizontal sheet-like bodies along bedding planes and zones of brecciation ; and in vertical or highly-inclined deposits filling joints, faults, and crevices widened by solution (gash veins). The ore-bodies often extend in comparatively narrow belts for long distances, forming the so-called runs. Such runs are controlled by structural features in the containing rocks. Both actual replacement (metasomatism) and cavity-filling have contributed to the formation of the ore-bodies.

The deposits generally carry both galena and blende, the latter more particularly in the deeper zones, so that many mines formerly yielding lead ore are now producing mainly zinc ore. Pyrite and marcasite are common associates, chalcopyrite is less frequent. Oxidized ores are found near the surface. In places the galena carries a little silver, but on the whole the deposits are classed as non-argentiferous, and the lead produced is marketed as soft lead.

The ores are generally believed to have been formed by the action of atmospheric waters circulating at shallow depths, though some regard them as originating from the action of ascending thermal solutions. The mineral association, however, does not favour this theory. There is an extensive literature dealing with this question.

South-eastern Missouri [62/p. 104] [64] [65].—The deposits in this region were the scene of the earliest lead mining in the United States, having been discovered and worked in the early part of the eighteenth century. In recent years the output has been very large, and at the present time the district produces about one-third of the total lead of the United States. Zinc ore is practically absent, so that this area is essentially a lead producer.

The deposits are contained in more or less horizontal Cam-

brian strata, consisting of dolomites and shales resting upon the basal La Motte sandstone. The ore-bodies occur at two horizons, the chief being the Bonneterre dolomite, immediately overlying the sandstone, while the second, less important, one is the Potosi dolomite at the top of the Cambrian sequence.

In the upper formation, which was naturally the earliest worked, the ore occurs chiefly as veins and pipes, along joints and bedding planes widened by solution, and in the residual deposits covering the surface. Its distribution is very irregular. In the Bonneterre, on the other hand, the galena is mainly disseminated as a metasomatic replacement through the dolomite, though also occurring to some extent in the upper part of the formation in the form of veins, sheets and irregular masses filling joints, bedding planes, and other openings. The disseminated ore-bodies tend to follow certain directions and often reach large dimensions, the mine workings in some cases being very big.

The upper deposits were largely exhausted before the discovery of the disseminated ore in 1864, but are still mined to some extent at Potosi, Palmer and Valle. It is the disseminated deposits, however, which have supplied by far the greater part of the lead mined for many years past, and have placed this district in the forefront of the lead-producing regions of the world.

The galena is associated with a little pyrite and sometimes chalcopyrite, but zinc ore is practically absent. In places a nickel-cobalt sulphide, *linnacite*, occurs, and is recovered in a pyritic concentrate, locally known as "sulphide," which is separated from the galena. Calcite is the usual gangue mineral, but in the Potosi barytes is found.

The crude ore produced in 1917 yielded 5·03 per cent. of concentrate, and had an average recoverable lead content of only 3·5 per cent., being the lowest grade of lead ore worked in the United States. Owing, however, to the enormous tonnage mined, nearly 6,000,000 tons, the quantity of lead produced exceeded that of any other state.

South-western Missouri (Joplin district) [62/p. 115] [66].—This district lies around the city of Joplin, after which place it is usually named. It embraces an area of about 1,000 square

miles, situated principally in Missouri, but including also neighbouring portions of Kansas and Oklahoma. The principal mining camps are at Aurora, Granby, Webb City, Alba, Neck, Joplin, Galena, Badger, Quapaw and Miami. The deposits were discovered in 1850 and were for many years mined only for lead ore; zinc ore was produced in 1870, since which time it has become increasingly important, and at the present day is entirely predominant. This district has yielded considerably over 1,000,000 tons of lead concentrate and 5,000,000 tons of zinc concentrate. The crude ores are now said to average about 5·0 per cent. of concentrate, but were formerly much richer.

The deposits are mineralizations of brecciated chert, and occur chiefly in the Boone formation of Lower Carboniferous (*Mississippian*) age, consisting of from 250 to 350 ft. of limestone and chert. They are found also in the overlying Chester and Cherokee formations, and in the underlying Kinderhook. Near the surface the ore-bodies occur as elongated lenses or irregular masses in or around old sink holes and caverns filled with clay and brecciated chert (*broken ground*), while below, at depths of from 150 to 300 ft., they are found as more or less horizontal sheets or blanket veins (*sheet ground*) in a brecciated cherty member of the Boone formation. This ground is from 6 to 15 ft. thick. In the underlying Kinderhook rocks disseminated ore occurs but is practically unworked.

In the upper deposits galena predominates, and large bodies of this ore have been mined. In the sheet ground, which is now the chief source of ore, blende is the prevailing mineral, and at the present time this area ranks chiefly as a producer of zinc.

Wisconsin-Iowa-Illinois District [67] [68].—The ores of this region occur principally in the Galena dolomite and in the upper part of the underlying Platteville or Trenton limestone of Ordovician age. The former, which is from 250 to 275 ft. thick, is the main ore-bearing horizon. The beds are gently inclined and mining operations extend down to a depth of about 200 ft. from the surface. This district is noted for the occurrence of ore in flats and pitches, bodies formed of a central flat sheet from the margins of which ore extends down-

wards in an inclined or step-like manner. It is found also in gash veins occupying vertical joints or crevices enlarged by solution, as flat sheets along bedding planes, and disseminated through the limestone as a metasomatic replacement. The first ore obtained from this district occurred in the superficial residual clays, where it was discovered towards the close of the seventeenth century.

The upper zones of the ore-bearing beds are characterized by galena and zinc carbonate, while below blende predominates, associated with some galena and marcasite. Calcite is the common gangue mineral, but dolomite and barytes are found also. Lead ore occurs most abundantly in the southern portion of the district, in the vicinity of Galena, Illinois; and Dubuque, Iowa, while zinc ore is more important in the north-east, where the lower beds of the ore-bearing horizon are chiefly exposed. At the present time most of the lead produced comes from the mines situated around Mineral Point and Platteville, in Wisconsin.

Other places in the Mississippi Valley where lead ores are mined are Central Missouri and Northern Arkansas, but these deposits are small as compared with those already considered and have not been exploited to any important extent.

The Rocky Mountains and Pacific Slope

Argentiferous lead ores are widely distributed in this region, and have furnished material for a thriving smelting and refining industry. At the present time, however, the mining is of less importance than formerly owing to the exhaustion or impoverishment of many of the deposits, and several of the smelters have closed down or now rely largely upon imported ores.

This region is famous for a wonderful development of limestone replacement deposits, some of which have been truly remarkable and rank among the great ore-deposits of the world. An outstanding feature of these deposits has been the extensive development of oxidized ores, large quantities of which have been raised. The richly argentiferous character of the galena is notable, and considerable quantities of gold slao have been obtained from some of the deposits.

Arizona.—Silver-lead deposits have been worked in this state since early times in the history of American mining, though the ores were raised chiefly for their silver content. Operations were conducted chiefly at Mowry, Eureka, Castle Dome, and Tombstone, in Southern Arizona, but practically ceased in the eighties. In recent years the district has received renewed attention.

The Hualpai mining district in North-western Arizona contains veins in Pre-Cambrian schists and gneisses, associated with granite and granite-porphyry. The upper parts of the deposits yielded rich silver ores, but primary sulphides were encountered in depth. This ore, which carries pyrite, galena, blende and chalcopyrite, contains 8 per cent. lead and 5–10 per cent. zinc, together with 15 oz. of silver to the ton, and some gold.

California.—The only really important lead-producing district in this state has been Cerro Gordo, in Inyo County, which at one time had a considerable output, reaching its maximum in 1874, after which it declined and ultimately ceased owing to impoverishment of the deposits and troubles due to litigation. After a long period of idleness the district was reopened in 1906. The ores are contained in steeply-dipping veins traversing slate and limestone intersected by various intrusive rocks. The veins are very varied in width, rapidly swelling and pinching, a character which makes their mining very uncertain and speculative. Large quantities of anglesite and cerussite were obtained from the upper parts of the veins, giving place to galena in depth. The ore ran high in silver, some of it containing as much as 140 oz. to the ton.

Lead ore has been obtained also from the Darwin district, where there are large deposits yielding argentiferous carbonate and sulphide. In 1917 the state yielded 65,596 tons of concentrate.

Colorado.—For many years this state was the leading producer of lead in the United States, though the output has now considerably decreased. The chief producing district has been Leadville, other important ones being Aspen, Monarch, Redcliff, Ten Mile, Silver Cliff, and the San Juan region. Colorado produced in 1917, 440,909 short tons of lead concentrate.

The Leadville district [1] [69], discovered in 1875, has yielded an enormous production of lead and silver, together with zinc, copper, gold, and manganiferous iron ore. The output reached a maximum in 1883, declined rapidly in the nineties, but was resuscitated in 1900. In latter years important bodies of oxidized zinc ores, calamine and hemimorphite, have been discovered [70].

The deposits consist chiefly of replacements in limestone at the contact with intrusive sheets of porphyry, but ore has been found also in fault fissures traversing the limestones and extending into the underlying Cambrian quartzite. The main ore-bearing horizon is in the Blue Limestone, of Lower Carboniferous age, along its contact with the overlying White Porphyry. There is a second, lower, contact with a smaller, more irregular, Gray Porphyry both in the Blue Limestone and in an underlying White Limestone of Silurian age, but this is less important. Some of the ore-bodies reached enormous dimensions. The rocks have been much folded and displaced by faults of considerable throw so that the structure is somewhat complex.

Emmons came to the conclusion that the ores were formed by aqueous solutions derived from above, most probably from the neighbouring porphyries, but the more recent observations of others favour the theory of ascending solutions from an underlying granite.

At first the mines yielded large quantities of oxidized lead ores, cerussite and anglesite, with some pyromorphite, and rich silver minerals, associated with oxides of iron and manganese, but these gave place at lower levels to mixed sulphide ore, consisting of blende and pyrite with galena and chalcopyrite. Considerable quantities of gold have been produced also. At the present time lead ore proper constitutes only about 5 per cent. of the output of the district; considerable quantities of oxidized zinc ore are raised, but the preponderating product is a mixed sulphide ore consisting chiefly of blende and pyrite, with some galena and chalcopyrite.

The Leadville deposits form part of a belt which extends in a north-easterly direction for eighty miles into Boulder County, and similar ore-bodies occur in the Ten Mile, Redcliff, and

other districts. In the northern end of the belt gold veins, telluride veins, and tungsten veins are found, probably representing a higher zone of deposition than that of the lead-zinc deposits occurring farther south.

The Aspen district, in Pitkin County [71] [72], ranks, after Leadville, as the second largest producer of lead ore in Colorado. It came into prominence in 1884, with the discovery of veins carrying rich silver sulphides, and was at first essentially a silver camp, but the mining declined in 1893 with a drop in the price of that metal. Subsequently lead ore became important, while in recent years the production of blende has increased. The deposits chiefly follow faults in the Carboniferous limestone, which the ore has replaced. In addition to the veins carrying galena and blende there are others containing barytes.

In 1917 the production of lead concentrate was 74,389 tons. The ore mined carried 9–10 per cent. lead and 3 oz. of silver to the ton, present mainly as polybasite.

The deposits of the Monarch and Chalk Creek districts, in Chaffee County, formerly yielded large quantities of carbonate ore, but at present the product is mainly a mixed ore consisting of blende, galena, pyrite and chalcopyrite. The lead concentrate produced in 1914 amounted to about 1,000 tons.

In the Silver Cliff district, in Custer County [73], deposits containing galena, blende, tetrahedrite, argentite, etc., in a gangue of calcite, barytes and quartz, occur at the contact between rhyolitic tuff and Pre-Cambrian gneiss. In the Geyser Mine the ore-body has been worked to a depth of over 2,000 ft.

The San Juan region in South-west Colorado, though perhaps best known for its yield of gold and silver, is also the site of important lead and zinc deposits. The chief mining is located in the districts of Telluride, Ouray, Silverton, Lake City, Rico, Needle Mountains, La Plata and Creede. There is an extensive literature relating to these deposits, and the region includes many well-known mines, such as the Enterprise [74], the Camp Bird [75], noted more especially for its gold values though some lead is recovered, and others.

The region is composed largely of a thick mass of Tertiary

volcanic rocks overlying Palæozoic and Mesozoic sediments, into which are intruded masses of monzonite. The ores are contained in a series of fissure veins, many of which have been traced continuously for several miles. In addition there are replacement deposits in the sedimentary formations and contact deposits at the margins of the intrusive rocks. Some of the ore-bodies have been mined to depths of several thousand feet. The genesis of the deposits is attributed to solutions ascending from deep-seated magmatic sources.

The chief values are in gold and silver, but in some places important deposits of lead and zinc have been mined, the ores of galena and blende being usually associated with more or less copper in the form of tetrahedrite. The gangue minerals comprise quartz, calcite, rhodochrosite, rhodonite, barytes and fluorspar. The veins are often beautifully banded, and vary in width from a few inches up to many feet.

The main lead occurrences are in the Silverton district, with an annual lead production of about 5,000 tons; Rico district, where the ores occur chiefly in bedded veins (blankets), following lines of stratification; Lake City district, which has yielded upwards of 40,000 tons of lead from veins carrying galena, pyrite, blende and tetrahedrite, the last being rich in silver; and the Creede district, where veins intersecting rhyolite carry considerable quantities of galena and blende in a gangue of quartz, barytes and fluorspar.

Idaho.—This state produced in 1917, 583,439 short tons of lead concentrate, principally from the Cœur d'Alene district. Lead ore was discovered here in 1884, in veins traversing a thick series of folded and faulted Pre-Cambrian quartzites and slates, with some limestone, invaded by large monzonitic intrusions. The ores, which occur both as fissure fillings and as metasomatic replacements of the bordering country rocks, consist of argentiferous galena, accompanied by blende and pyrite, associated with large quantities of siderite and subordinate quartz. Although the galena may sometimes occur massive the ore is usually an aggregate of galena and siderite. The ore-bodies are large and the veins remarkably persistent, the Bunker Hill vein, for example, being traceable for 7,000 ft. Mining has been carried to depths of over 2,500 ft.

The crude ore, which contains on an average 8 per cent. lead and 5 oz. of silver to the ton, is classified as lead ore and as lead-zinc ore. The lead concentrate yields 50 per cent. lead and 30 oz. of silver to the ton.

In 1917 the Cœur d'Alene district produced 186,004 tons of lead, 38,862 tons of zinc, 1,438 tons of copper, 11,241,126 oz. of silver, and $88,683 worth of gold, having a total value of $50,054,297. The principal mines are the Bunker Hill and Sullivan, the Standard-Mammoth, the Morning, and the Hercules.

In the Wood River district the ores occur in thin veins traversing Carboniferous calcareous shale in the neighbourhood of a diorite intrusion. The ore shoots are very irregular and their mining uncertain. The ore consists of galena, often massive, blende, and argentiferous tetrahedrite, with a little pyrite and chalcopyrite, in a gangue composed chiefly of siderite or a closely allied carbonate. A little gold is usually present. The crude ore is concentrated to a product yielding 33 per cent. lead and 50 oz. of silver to the ton. The chief mines are the Minnie Moore, the Crœsus, the Bullion, the Red Elephant, and the Red Cloud.

At South Mountain argentiferous galena and blende occur in a deposit at the contact of limestone and diorite, furnishing a good example of this class of ore-body.

Montana.—In the contact zone of the Helena batholith there are several lead-bearing veins, one of which, the well-known Alta vein, is said to have yielded over $32,000,000 worth of lead and silver and to be one of the greatest silver-lead deposits in the world.

The ore raised in this district at present is a mixture of argentiferous galena and blende with some copper ore. In 1917 the lead content of the ore mined was, in lead ores, 2,778 tons; in lead-zinc ores, 5,728 tons; in zinc ores, 1,770 tons; and in all other ores, 700 tons, making a total of 10,976 short tons [81/p. 888].

At Elkhorn there are large replacement deposits in limestone from which considerable quantities of oxidized and sulphide ores have been obtained.

Nevada.—By far the most important lead-producing dis-

trict in this state has been Eureka, though at present the output is insignificant, amounting only to about 150 tons of concentrate annually. The mines were reopened in 1906 after a period of abandonment.

The deposits consist of large replacement bodies in limestone along its faulted contact with quartzite. Considerable quantities of oxidized ores, including arsenates, phosphates and molybdates, were raised at one time, but in depth the ore-body became sulphidic. The galena is richly argentiferous and some gold is present also.

At the present time the bulk of the lead output of Nevada comes from the Pioche, the Yellow Pine, and the Cherry Creek districts.

New Mexico.—Like many other of the Western States, New Mexico shows a decreasing output of lead ore, and the mining industry is far less important than formerly. The best-known undertakings are the Magdalena Mines, where large deposits occur in Palæozoic limestone at the contact of a granite-porphyry. The ore-bodies, which are lenticular, follow the bedding planes of the limestone, and are found up to 40 ft. in thickness. There are five ore-bearing horizons, only one of which, however, is important. In the oxidized zone the yield was mainly lead and silver, but in depth large bodies of blende were encountered.

At present the leading production of lead from this state comes from the Grant and the Cook districts, where the ore occurs in fissure veins traversing granite.

Utah.—This state produced in 1917, 696,421 short tons of lead concentrate. Salt Lake City is the seat of an important lead-smelting industry.

The deposits are situated in the Bingham, Park City, Tintic, and Frisco districts, the first mentioned being now the leading producer.

In the Bingham district the deposits occur as replacements in limestone at its junction with quartzite or porphyry. The oxidized zone, carrying carbonates and sulphates, extends to considerable depths.

In the Park City district [76] the ores occur both as replacement bodies along bedding planes in limestone and in fissures

traversing a series of folded and faulted limestones, quartzites, and shales of Carboniferous and later ages, in the neighbourhood of large dioritic intrusions. The fissure deposits, which carry galena, blende, tetrahedrite and chalcopyrite, in a gangue of quartz and jasperoid, with fluorspar, calcite and rhodonite, have been worked to considerable depths, but there contain more zinc and copper. The richest lead ore-bodies have been the bedded deposits. Since 1877 this district has produced well over a million ounces of silver and about half a million tons of lead. In recent years the output of zinc and copper has increased. The concentrate produced at present contains 12 per cent. lead, 6–8 per cent. zinc, 9 oz of silver to the ton, and some gold and copper.

In the Tintic district [77], south of Salt Lake City, the ore-bodies consist of large replacement deposits and fissure fillings along bedding planes, fissures and joints in limestone, in the vicinity of a monzonite intrusion. The ore consists of galena, blende, and, locally, enargite, with quartz, jasperoid, carbonates and barytes. The galena is rich in silver, while gold accompanies the occurrence of enargite.

In the Frisco district veins and replacement deposits occur in Palæozoic limestones, shales and quartzites, overlain by andesitic lavas and intruded by monzonite. Veins in the intrusive carry chiefly copper and zinc.

The celebrated Horn Silver Mine, in Beaver County, is still a producer. The deposit occurs at the junction of limestone and andesite, and there is a considerable replacement of the former. The oxidized zone extends to a depth of about 600 ft. and carries large quantities of anglesite. Complex sulphates, like *plumbojarosite*, are rather abundant. This mineral, which is a basic sulphate containing lead and iron, has been found elsewhere in Utah [78].

The Cactus Mine, which at present raises mainly copper, was at one time an important producer of lead and silver.

Consumption of Lead in the United States

The United States, although the largest producer of lead ore in the world, imports considerable quantities in order to satisfy her large smelting industry. The decline of lead mining in

the Western States, due to the abandonment of many of the largest mines towards the close of the last century, had a serious effect upon the large smelters which had grown up with the mining industry, and many had to close down, or to continue operations with the help of imported ores. The magnitude of the consumption of lead by the United States may be gathered from the following figures for 1917, in short tons:

Recoverable from domestic ores		548,450
Imports from all sources		78,272
In warehouses, January 1, 1917		12,369
		639,091
Total exports	98,877	—
Stock in warehouses, December 31, 1917	26,909	125,786
Consumption	—	513,305

Tables XXXI, XXXII and XXXIII give details of some recent import and export trade of the United States.

Table XXXI

Imports of Dressed Lead Ore into the United States (years ending June 30th) *

In short tons (2,000 lb.)

	1916.	1917.	1918.	1919.
From British countries :				
Canada	15,840	8,777	26,050	11,618
Australia	21,308	—	—	—
Other British countries .	303	2,880	9,517	—
Totals (British) . .	37,451	11,657	35,567	11,618
From foreign countries :				
Mexico	51,958	79,357	72,879	78,424
Chile	6,982	9,117	1,864	919
Other foreign countries .	3,160	13,813	399	7,645
Totals (foreign) . .	62,100	102,287	75,142	86,988
Grand totals . .	99,551	113,944	110,709	98,606

* *Foreign Commerce and Navigation, U.S.A.*

Table XXXII

Imports of Lead into the United States *

In short tons (2,000 lb.)

	1915.	1916.	1917.	1918.†	1919.†
From British countries :					
United Kingdom . .	2	2	54	—	—
Canada, etc. . . .	35	135	172	2,506	44
Totals (British) . .	37	137	226	2,506	44
From foreign countries :					
Mexico	346	2,400	4,107	2,705	5,052
Other foreign countries .	22	79	233	29	11
Totals (foreign) . .	368	2,479	4,340	2,734	5,063
Grand totals . .	405	2,616	4,566	5,240	5,107

* *Commerce and Navigation of United States.*

† Calendar years.

Table XXXIII

Exports of Lead from the United States *

Pigs, bars, plates and old

Short tons (2,000 lb.)

	1915.	1916.	1917.	1918.	1919.
To British countries :					
United Kingdom . .	42,864	22,057	3,064	61,107	49,893
Canada	10,258	31,369	55,149	12,562	8,059
Other British countries .	679	667	—	—	—
Totals (British) . .	53,801	54,093	58,213	73,669	57,952
To foreign countries . .					
France	8,585	2,367	510	2,530	1,412
Russia	13,886	14,938	20,981	14,747	304
Japan	4,550	14,650	4,717	3,950	7,029
Other foreign countries .	15,690	17,057	9,543	12,211	8,236
Totals (foreign) . .	42,711	49,012	35,751	33,438	16,981
Grand totals . .	96,512	103,105	93,964	107,107	74,933

* *Foreign Commerce and Navigation of the United States,* and *Monthly Summary of Foreign Commerce of the United States.* (The figures include lead produced from foreign ore ; years ending June 30th.)

SOUTH AMERICA

Several of the South American States are producers of lead ore, notably Argentine, Bolivia, Chile, Colombia and Peru, and substantial amounts have been exported to the United Kingdom and the United States.

Most of the deposits occur in veins of a similar type to those of Mexico, already considered, in which the mining of lead has succeeded that of silver. Important mining localities are Cerro de Potosi, in Bolivia; San José, in Chile; Cerro de Pasco, in Peru, and many others.

719

APPENDIX

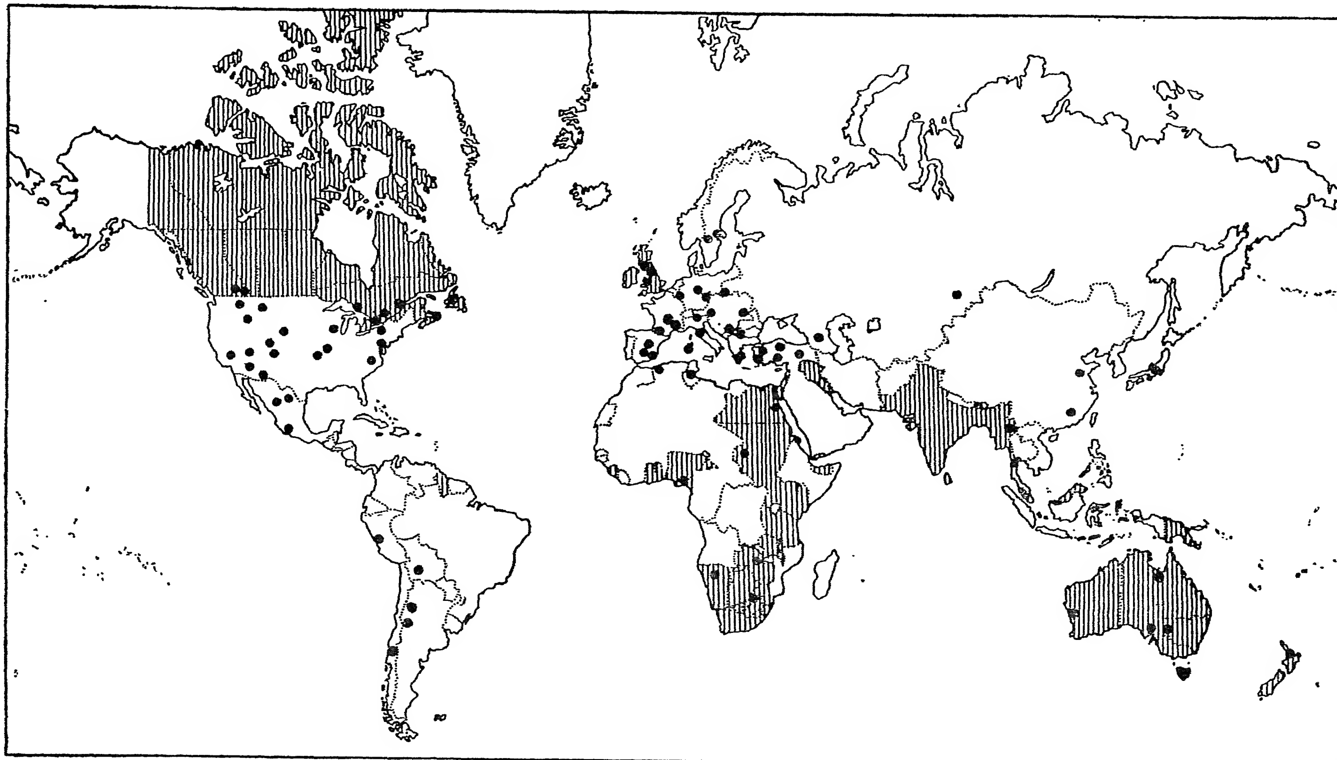
LEAD POISONING

A great drawback to the use of lead, either in the form of metal or its compounds, is its poisonous character. Lead poisoning is quite common, for example, among workpeople connected with the preparation and use of whitelead. It may be incurred, also, through drinking water conveyed by lead pipes, for which reason such pipes are sometimes tin-lined.

The symptoms of the disease are pains in the abdomen, constipation, loss of appetite, thirst, nervous prostration, known as "lead palsy," epileptic fits and paralysis. A blue line which forms on the edges of the gums is due to deposition of lead sulphide.

A simple treatment for lead poisoning is to give mustard as an emetic, followed by Epsom or Glauber salts. Large doses of milk, containing white of egg, are beneficial. A good antidote is *weak* sulphuric acid, but this should be administered with caution.

The smoke from lead smelting furnaces, containing, as it does, such substances as lead, arsenic, sulphur trioxide, and sulphur dioxide, is highly injurious to animal and vegetable life.



Map showing the Lead-bearing Districts referred to in the Text. (British Empire and Protectorates shaded.)

REFERENCES TO LITERATURE ON LEAD

The Publications are referred to by Numerals in the Text

[1] S. F. Emmons, "Geology and Mining Industry of Leadville," *Monograph U.S. Geol. Survey*, No. 12 (1886).

[2] W. R. Ingalls, "The Distribution and Production of Lead," *Mineral Industry* for 1893, vol. ii, p. 381.

[3] J. E. Spurr, "Who Owns the Earth?" *Eng. Min. Journ.*, Feb. 7, 1920.

[4] H. O. Hofman, *The Metallurgy of Lead*, New York, 1918.

[5] Edward Thorpe, *Dictionary of Applied Chemistry*, London, 1912.

[6] C. D. Holley, *The Lead and Zinc Pigments*, New York, 1909.

[7] Arthur H. Church, *The Chemistry of Paints and Painting*, 4th ed., London, 1915.

[8] Report of the Controller of the Department for the Development of Mineral Resources in the United Kingdom. Published by the Ministry of Munitions of War, London, 1918.

[9] *Mines and Quarries*, General Report by Chief Inspector of Mines, pt. iii, issued annually by the Home Office.

[10] J. H. Collins, "Observations on the West of England Mining Region," *Trans. Roy. Geol. Soc. Cornwall*, vol. xiv (1912).

[11] J. H. Collins, "Lead-bearing Lodes of the West," *Trans. Roy. Geol. Soc. Cornwall*, vol. xii, pp. 690–7.

[12] Clement Le Neve Foster, "The Lode at Wheal Mary Ann," *Trans. Roy. Geol. Soc. Cornwall*, vol. ix, pp. 152–7.

[13] T. Morgans, "Notes on the Lead Industry of the Mendip Hills," *Trans. Inst. Min. Eng.*, vol. xx (1902), p. 478.

[14] L. J. Spencer, "Leadhillite in Ancient Lead Slags from the Mendip Hills," *Report British Assoc.* for 1898, p. 875.

[15] L. C. Stuckey, "Lead Mining in Derbyshire," *Mining Magazine*, vol. xvi (1917), p. 193.

[16] Cyril E. Parsons, "The Deposit at the Mill Close Lead Mine, Darley Dale, Matlock," *Trans. Fed. Inst. Min. Eng.*, vol. xii (1896), p. 115.

[17] C. B. Wedd and G. Cooper Drabble, "The Fluorspar Deposits of Derbyshire," *Trans. Inst. Min. Eng.*, vol. xxxv (1908), p. 501.

[18] T. Sopwith, "On the Lead-mining Districts of the North of England," *Trans. North of England Inst. Min. Eng.*, vol. xiii (1864), p. 187.

[19] Henry Louis, "Lead Mines in Weardale, Co. Durham," *Mining Magazine*, vol. xvi (1917), p. 15.

[20] William Wallace, *The Laws which Regulate the Deposition of Lead-ore in Veins; illustrated by an examination of the Geological Structure of the Mining District of Alston Moor*, London, 1861.

[21] W. Nall, "The Alston Mines," *Trans. Inst. Min. Eng.*, vol. xxiv (1903), p. 392.

[22] John Postlethwaite, *Mines and Mining in the Lake District*, 3rd ed., Whitehaven, 1913.

[23] G. H. Morton, "The Geology and Mineral Veins of the Country round Shelve, Shropshire," *Proc. Liverpool Geol. Soc.*, 1869.

[24] H. E. Roscoe, "On two new Vanadium Minerals," *Proc. Roy. Soc.*, vol. xxv (1876), p. 3.

[25] A. Strahan, "Geology of the Coasts adjoining Rhyl, Abergele, and Colwyn" (Explanation of Quarter Sheet 79 N.W.), *Memoirs Geological Survey*, 1885.

[26] A. Strahan, "Geology of the Neighbourhoods of Flint, Mold, and Ruthin" (Explanation of Quarter Sheet 79 S.E.), *Memoirs Geological Survey*, 1890. Supplement in 1898.

[27] Warrington W. Smyth, "On the Mining District of Cardiganshire and Montgomeryshire," *Memoirs Geological Survey*, vol. ii, pt. 2 (1848), p. 655.

[28] Clement Le Neve Foster, "Notes on the Van Mine," *Trans. Roy. Geol. Soc. Cornwall*, vol. x (1879), p. 33.

[29] G. W. Lamplugh, "Economic Geology of the Isle of Man," *Memoirs Geological Survey*, 1903.

[30] John Mitchell, "The Wanlockhead Lead Mines," *Mining Magazine*, vol. xxi (1919), p. 11.

[31] Special Reports on the Mineral Resources of Great Britain; vol. ii, Barytes and Witherite, 2nd ed. (1916), p. 88, *Memoirs Geological Survey*.

[32] Warrington W. Smyth, "On the Mines of Wicklow and Wexford," *Records of the School of Mines*, vol. i, pt. 3 (1853), *Memoirs Geological Survey*.

[33] J. Coggin Brown, "Geology and Ore Deposits of the Bawdwin Mines," *Records of the Geol. Surv. of India*, vol. xlviii, pt. 3, (1917), pp. 121–78.
[34] *Imperial Institute Report on the Results of the Mineral Survey in Southern Nigeria for* 1905–6 (1910), pp. 21–5.
[35] *Imperial Institute Report on the Results of the Mineral Survey in Southern Nigeria for* 1908–9 (1911), pp. 10–12.
[36] Stanley C. Dunn, "Notes on the Mineral Deposits of the Anglo-Egyptian Sudan," *Sudan Geological Survey Bulletin*, No. 1, pp. 11, 12 (1911).
[37] Wm. Versfeld, "The Base Metal Resources of the Union of South Africa," *Memoir No.* 1, *Department of Mines and Industries*; also *Mining Magazine*, Dec. 1919, p. 372.
[38] O. E. Leroy, Summary Report for 1909, *Geological Survey of Canada* (1910), pp. 131–3.
[39] J. B. Jaquet, "Geology of the Broken Hill Lode and Barrier Ranges Mineral Field, N.S.W," *Memoir Geological Survey, N.S.W.*, No. 5 (1894).
[40] Anon., *Mining Magazine*, vol. xxi (1919), p. 351.
[41] L. Hills, *Geological Survey Bulletin*, No. 19, Department of Mines, Tasmania (1915).
[42] L. Hills, *Geological Survey Bulletin*, No. 23, Department of Mines, Tasmania (1915).
[43] W. H. Twelvetrees and L. K. Ward, *Geological Survey Bulletin*, No. 8, Department of Mines, Tasmania (1910).
[44] Ch. Timmerhans, *Les gîtes métallifères de la région de Moresnet*, Liège, 1905.
[45] J. Schmid, "Bilder von den Erzlagerstätten von Przibram," Austrian Agricultural Department, Vienna, 1887.
[46] Herman Müller, "Die Erzgange des Freiberger Bergrevieres," *Erlauterungen zur geol. Special-Karte Saschsens*, Leipzig (1901), p. 350.
[47] F. Klockmann, "Beitrage zur Erzlagerstättenkunde des Oberharzes," *Zeits. für prakt. Geol.* (1893), pp. 466–71.
[48] B. Baumgurtel, *Oberharzer Gangbilder*, Leipzig (1907), p. 23.
[49] W. Lindgren and J. D. Irving, "The Origin of the Rammelsberg Ore Deposit," *Economic Geology*, vol. vi (1911), pp. 303–13.
[50] R. Beck, *Lehre von den Erzlagerstätten*, vol. ii (1909), p. 257.
[51] G. Gurich, "Zur Genesis der oberschlesischen Erzlagerstätten, *Zeits. für prakt. Geol.*, 1903, pp. 202–5.

[52] A. Sachs, "Die Bildung der schlesischen Erzlagerstätten," *Centralblatt für Min.*, 1904, pp. 40–9.
[53] John Kirsopp, "The Mineral Resources of the Near East," *The Near East*, Aug. 15, 1919.
[54] "Austrian Mining in Serbia," *Engineering and Mining Journal*, Nov. 4, 1916, p. 814.
[55] Norman M. Penzer, "The Minerals of Anatolia," *The Mining Magazine*, vol. xxi (1919), pp. 78, 79.
[56] G. Maitland Edwards, "Notes on Mines in the Ottoman Empire," *Trans. Inst. Min. and Met.*, vol. xxiii (1913–14), pp. 197, 198.
[57] Anon., "The Mineral Resources of Asia Minor," *The Mining Journal*, Oct. 15, 1910, pp. 1202–3.
[58] A. S. Wheler and S. Y. Li., "The Shiu-Ko-Shan Zinc and Lead Mine," *Mining Magazine*, vol. xvi (1917), p. 91.
[59] W. Lindgren and W. L. Whitehead, "A Deposit of Jamesonite near Zimapan, Mexico," *Economic Geology*, vol. ix (1914), p. 435.
[60] W. R. Ingalls, *Lead and Zinc in the United States*, New York, 1908.
[61] *Mineral Resources of the United States for* 1917, pt. 1, *U.S. Geological Survey.*
[62] E. R. Buckey, "Lead and Zinc Deposits of the Ozark Region," in *Types of Ore Deposits*, p. 103, San Francisco, 1911.
[63] H. F. Bain and C. R. Van Hise, "Preliminary Report on the Lead and Zinc Deposits of the Ozark Region," *Twenty-Second Ann. Report, U.S. Geological Survey*, pt. 2 (1901).
[64] E. R. Buckley, "Geology of the Disseminated Lead Deposits," *Missouri Bureau of Geology and Mines*, vol. ix, pts. 1 and 2 (1909).
[65] A. Winslow, *Missouri Geological Survey*, vol. vii (1895).
[66] A. Winslow, *Missouri Geological Survey*, vol. vi (1894).
[67] H. F. Bain, "Flats and Pitches of the Wisconsin Lead and Zinc District," in *Types of Ore Deposits*, p. 77, San Francisco, 1911.
[68] H. F. Bain, "Zinc and Lead Deposits of the Upper Mississippi Valley," *Bulletin U.S. Geol. Survey*, No. 294 (1906), pp. 129–42.
[69] S. F. Emmons and J. D. Irving, "The Downton District," *Bulletin U.S. Geol. Survey*, No. 320 (1907).
[70] G. M. Butler, "Some Recent Developments at Leadville," *Economic Geology*, vol. vii (1912), pp. 315–23; vol. viii (1913), pp. 1–18.

[71] J. E. Spurr, *Monograph U.S. Geol. Survey*, No. 31 (1898).

[72] J. E. Spurr, "Ore Deposition at Aspen, Colorado," *Economic Geology*, vol. iv (1909), pp. 301–20.

[73] S. F. Emmons, "The Mines of Custer County, Colorado," *Seventeenth Ann. Report, U.S. Geol. Survey*, pt. 2 (1896), p. 461.

[74] T. A. Rickard, "The Enterprise Mine, Rico, Colorado," *Trans. American Inst. Min. Eng.*, vol. xx (1897), pp. 906–80.

[75] C. W. Purington, "The Camp Bird Mine," *Trans. American Inst. Min. Eng.*, vol. xxxiii, pp. 499–528.

[76] J. M. Boutwell, "Geology and Ore Deposits of Park City District, Utah," *Professional Paper U.S. Geol. Survey*, No. 77 (1912).

[77] G. W. Tower, Jnr., and G. O. Smith, "Geology and Mining Industry of the Tintic District, Utah," *Nineteenth Ann. Report, U.S. Geol. Survey*, pt. 3 (1898), pp. 603–785.

[78] B. S. Butler, "Occurrence of Complex and Little Known Sulphates and Sulpharsenates on Ore Minerals in Utah," *Economic Geology*, vol. viii (1913), p. 311.

[79] J. W. Gregory, "The Geological Plan of Some Australian Mining Fields," *Sci. Prog.*, July, 1906, pp. 15–18.

[80] E. S. Moore, "Observations on the Geology of the Broken Hill Lode, New South Wales," *Econ. Geol.*, vol. xi (1916), pp. 327–48.

[81] C. E. Siebenthal, "Lead in 1917," *Min. Res. U.S. Geol. Surv.*

[82] *Report of the Departmental Committee appointed by the Board of Trade to investigate and report upon the Non-Ferrous Mining Industry*, London, 1920.